EXPLORING AND MODELING THE LEVEL OF SERVICE OF PUBLIC TRANSIT IN URBAN AREAS: AN APPLICATION TO THE GREATER TORONTO AND HAMILTON AREA (GTHA), CANADA

EXPLORING AND MODELING THE LEVEL OF SERVICE OF PUBLIC TRANSIT IN URBAN AREAS: AN APPLICATION TO THE GREATER TORONTO AND HAMILTON AREA (GTHA), CANADA

By

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ABSTRACT

The design of policies for increasing public transit ridership is integral for strategies leading to sustainable transportation in large metropolitan areas. Assessing the availability of public transit (i.e. supply) as a viable mode of transportation can help in the design of such policies. In this respect, this study examines transit service intensity at the census tract level by assembling and analyzing a suitable GIS database for the Greater Toronto and Hamilton Area (GTHA). This research utilizes an improved version of the 'Local Index of Transit Availability' (LITA), which derives service levels based on the coverage, capacity, and frequency of the transit system. Transit service levels as measured by LITA, are linked to a number of socio-economic and spatial characteristics via a simultaneous auto-regressive (SAR) model. Results indicate that the core areas of municipalities were not necessarily well serviced by public transit. Suburban peripheral tracts and those adjacent to the shoreline were characterized by average transit service at best, and tracts adjacent to municipal borders indicated discontinuity in transit service. Furthermore, previous studies often overlooked the impact of spatial effects by utilizing the conventional OLS regression modeling technique. The use of the SAR model in this study corrected for that and enhanced the overall explanatory power of the modeled data. The estimation results indicate that variables such as population density, income, percentage of recent immigrants, percentage of young adults and percentage of elderly population are key variables to explain transit availability in the GTHA.

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CHAPTER ONE: Introduction

1.1.Background

Public transportation is typically operated by a city or regional government, in areas with population densities capable of sustaining the cost of the service. A high-quality public transit system can be an important factor in the economic well-being of an urban area. Proximity to transit usually raises the value of nearby residential and commercial properties, while investment in the infrastructure of transit services tends to stimulate employment growth (The Canadian Chamber of Commerce, 2006). It is suggested that population growth, escalating vehicle costs and the increase in awareness of environmental issues are among the main factors that could increase transit ridership levels in the future. However, currently, the personal automobile remains the preferred modal choice for most Canadians due to the convenience, flexibility and social perceptions associated with its use. Public transit conversely, is most often associated with restriction, over-crowding, infrequency, and lack of destinations. For transit to compete effectively with the personal automobile, it must provide an acceptable level of convenience, including greater coverage and more frequent service to peripheral areas.

While most of the existing research has been primarily focused on modelling and assessing areas of potential transit demand, some studies have opted to utilize or create their own measures of existing transit service intensity [see for example: Lao and Liu (2007); Fu and Xin (2007); Kittelson & Associates and URS, Inc (2001); Deka (2002), Rood (1998); Hillman (1997)]. Other studies have utilized measures to examine the relationship of spatial and socio-economic characteristics to transit ridership and service intensity [Taylor and Fink (2003); Cervero (2008); Morris (1981); Starrs and Perrins (1989)]. However, most of the existing studies were conducted for urban areas outside of Canada. As such, very little is known about the nature of the existing Canadian urban transit systems and the socio-economic factors which affect these systems. The research conducted for this thesis attempts to fill this gap by exploring and modeling the level of service of public transit in six individual regions in the Greater Toronto and Hamilton area (GTHA). This region is home to nearly half of the province's 12.5 million residents and is one of the fastest growing metropolitan areas in Canada (Metrolinx, 2009).

1.2. Objectives

The objective of this thesis is to make use of an improved version of the Local Index of Transit Availability (LITA), proposed by Rood (1998), to explore the spatial dimensions of transit service supply at the census tract scale. Index results are then used to determine the strength of relationships to socio-economic and spatial characteristics thought to influence levels of transit supply.

1.3. Contributions of the Thesis

The work presented in this thesis makes two distinct contributions to the existing literature. Unlike previous studies which used the standard LITA transit index, this study refines a few components of the tool in an effort to facilitate comparisons of the index application results in different jurisdictions. A further innovation introduced in this thesis is that transit supply as measured by LITA, is linked to socio-economic and spatial characteristics via a simultaneous auto-regressive (SAR) model to account for spatial effects in the data. More often than not, such effects are overlooked by previous studies, which relied heavily on the ordinary least square (OLS) regression formulation. Based on knowledge derived from the literature review provided in Chapter 2, the employed methods to study transit systems have not been used in previous studies.

1.4. Outline of the Thesis

This thesis proceeds with a review of the empirical literature on transit use, service intensity and availability. The components used for the computation of the LITA index are explained, and a summary of previous efforts relating the levels of transit availability to spatial and socio-economic characteristics is provided. The review also provides an overview of some of the strongest indicators of transit supply levels. Chapter 3 and 4 are presented in the context of the discussion presented in the literature review. Chapter 3 outlines the data requirements and methodology of the LITA index and presents the achieved results from the exploration of the refined LITA index for the six studied regions. Chapter 4 builds on the previous chapter by employing the obtained availability scores in a bivariate examination and multivariate regression analysis. This research concludes with some final discussion and an indication towards areas of potential future research.

CHAPTER TWO: Literature Review

2.1. Introduction

This chapter sets the context for the analysis of transit availability and supply in the GTHA as presented in the subsequent chapters. A review of the literature sheds light on several previous studies which have attempted to explain the factors influential towards, and responsible for transit service levels and relationships to the general public. A brief overview of current modal trends and transit policy is discussed first, followed by a review of previous attempts to study and model transit demand and levels of transit availability. While several methods have been employed, a preferred framework of measurement has not been defined. The LITA index, which was identified as appropriate to the demands of this study, is then introduced. The components used to derive the index calculations are reviewed and validated. Finally, as this research also has a focus on discerning relationships of transit availability to social and spatial characteristics of the population, the five variables used in the modelling process; population density, income, young adult age, elderly age, and recent immigrants, are explored and reviewed for the final section of this chapter.

2.2. Modal Choice

Public transportation is a system that provides an inexpensive means of mobility and accessibility to the mass public. However, the flexibility, convenience, and comfort of the personal automobile make it a classically preferred mode choice for individuals. In the United States, the number of carless households decreased from 11.4 million in 1960 to 10.6 million in 1990 despite a significant increase in the total number of households during this period (Pisarski 1996). Part of this trend is explained by the historically persistent low-pricing of automobile use. Pucher and Lefevre (1996) observed that drivers are not charged for congestion, pollution, and other externalities; fuel prices are reasonably affordable in the developed world; and access to driver's licenses is liberal. Moreover, Kaufmann (2000) indicated that the qualities of speed, individualism, and privatization defined the desire of car usage, whereas public transit was associated with restriction, slowness and crowdedness.

A strong determinant of modal choice is residential location. Most public transit systems are situated in highly urbanized areas. Rural communities thus, are typically excluded or severely restricted from services. Gray et al. (2001), concluded that the lack of provision and flexibility of services in rural locations, rendered many rural dwellers unwilling to consider public transport as an alternative. Additionally, the layout of various urbanized areas in North America is consistent with the characteristics of suburban sprawl, where low density and dispersed development characterizes the peripheries of an urban core. This type of development creates a high dependence on the private automobile and difficult circumstances for transit agencies hoping to attain ridership and plan efficient routings.

Implementing policies and incentives to encourage public transit use have been pursued at various intensities throughout the world. For example, Cullinane (2003) suggested the Hong Kong government was successful in suppressing the demand for private transport by implementing strict controls on parking and high costs for vehicle usage, while providing convenient and cheap public transport. Interest in remedial actions to discourage car use amongst North American cities has not been pursued as actively. However, planning strategies have begun to navigate towards transit-oriented development that situates housing, workplaces, and other urban activities within an easy walk of public transit (Cervero et al., 2004). Zhang (2006) observed when you increase a person's access of transit choices through more transit options they will be less reliant on their automobile.

2.3. Public Transit Availability

Achieving increased public transit ridership through the reduction of personal vehicle use first requires policy actions to increase transit availability and quality. Facilitation of these policies may be aided if transit agencies and municipalities are able to assess the areas which are in need of increased or revised service levels. Often, public transit inquiries are associated with the extensively studied field of determining transit demand. Transit demand applications are generally concerned with the measurement of existing transit structures and socio-economic characteristics of an area in order to delineate and estimate where transit services will likely be successful. Typically, the spatial data requirements and integration techniques for transit demand modelling encompass a combination of ridership data, transit service variables and socio-economic and demographic data inputs (Peng and Dueker, 1995). Several methods and scales have been employed for these types of investigations (see for example; Kimpel et al., 2006; Yao, 2007; Chatham Area Transit, 2008).

Previous attempts to assess existing levels of transit service intensity have been approached at a partial level, meaning, investigations tend to focus on specific aspects and components of transit services. A gap exists when deciphering a leading method of transit availability measurement. However, the general assumed measure of transit availability for several planning and transit agencies is a 400 metre buffered distance from a transit stop or route (Grengs, 2001; Kimpel et al., 2006). However, the assumption that a household has 'access' if within a 400 metre radial zone does not take into account external factors such as the frequency and destinations associated with the route. Thus, inclusion of transit system characteristics in a service availability assessment enables a more comprehensive measure of availability.

Several investigations have fashioned original tools of transit service intensity measure. For example, Lao and Liu (2007) interpreted the relative efficiency of specific bus routes through the design of an operational efficiency and spatial effectiveness score. Fu and Xin (2007) developed the Transit Service Indicator (TSI), used as a measure of quality of public transit service for a given individual taking a given trip, based on the integration of several performance measures. The Florida Department of Transportation enacted the Transit Level of Service indicator (TLOS), a quality-of-service measure defined by the percentage of time that an average person can use the transit service (Kittelson & Associates and URS, Inc. 2001). Other examples include, but are not limited to; A geographical information systems–based transit availability index (Deka, 2002), a time dimension focused transit accessibility analysis tool (Polzin et al., 2002), the Public Transport Accessibility Level (PTAL) index (Hillman, 1997, Wu and Hine, 2003, Bromley: The London Borough, 2008), and the method employed in this study; the Local Index of Transit Availability (LITA) (Rood, 1997).

2.4. The Local Index of Transit Availability (LITA)

Henk and Hubbard (1996) outlined the development of a transit availability index using factors designated as most effectively able to quantify the availability of service. The three factors proposed were capacity, frequency of service and areal coverage. Similarly, the LITA index is derived from the combination of these three factors. The LITA index was developed with the intention to provide interested parties with a visual and quantitative representation of transit service availability through a grade assignment system. LITA relates the amount of transit service in an area to the region's population and land area. A beneficial characteristic of the LITA index is the ability to assess transit intensity at several spatial levels for which population, transit and land area data are available. An additional benefit of the index is the ability to characterize results through the use of geographic information systems (GIS). LITA has been employed in several areas. Rood (1998) initially documented the use of the LITA index for Riverside County, California. Other areas of use include Bradford, England (Pennycook et al, 2001), Vancouver, Canada (Vancouver Transit Accessibility, 2007), and Addis Ababa, The Federal Democratic Republic of Ethiopia (Gebeyehu, and Takano, 2008). Furthermore, the index is advocated by organizations such as the United States Environmental Protection Agency (EPA) (EPA, 2009), the West Coast Environmental Law organization, British Columbia (West Coast Environmental Law, 2008), and the Sustainable Communities Network (Smart Growth Online, 2009).

Each of the factors designated for use in the computation of the LITA index are highly associated with transit availability and usage levels. Firstly, transit capacities dictate the quantity of passengers a system can accommodate. Most often, this is of extreme importance during peak travel hours. Transit service capacity is especially critical in large urban areas where there is typically not enough roadway capacity to rely on the personal vehicle during peak periods of travel (Henk and Hubbard, 1996). It has been reported that overcrowding and unreliable services are the biggest problems for the new found transit riders (Bouzane, 2008).

A second factor, frequency of transit service, refers to both the total hours of daily transit operation and the frequency with which this service is provided (headways between transit vehicles). Longer transit operating hours implies more service throughout the day; whereas, an increase in the frequency of transit service implies a decrease in initial wait time. Time involved waiting for a transit service can ultimately negatively affect individual's dispositions towards usage. Research into travel behaviour has determined that the disutility of out-of-vehicle wait time is perceived to be significantly more burdensome than in-vehicle travel time (Reed, 1995). These studies show in the perception of travelers, time spent waiting passes more slowly than an equivalent amount of objective time spent moving toward one‘s destination. Reed (1995) found that travelers perceive one minute of wait time as equivalent to 1.5 to 2 minutes of transport time. In a situation where transit patrons have the ability to select from multiple bus stops serving the same destination, choice riders will most likely walk to the bus stop associated with the greater service frequency (Kimpel 2006). Alshalalfah and Shalaby

(2007) studied the impact of frequency of service on riders in Toronto, Canada and found the higher the frequency of the transit service, the longer people are willing to walk to access transit. Furthermore, results show that high-frequency routes attract about three times as many riders as medium-frequency routes and four times of low-frequency routes.

The final factor, transit service coverage, provides some measure of the access to transit stops or routes throughout an urban area. Giuliano (2005) suggested the likelihood of being a regular transit user is higher for residents living near a transit stop. This was verified in a study by Yu-Hsin Tsai (2008) which found that transit stop proximity to both work and residence increased the probability of rail transit commuting in Taipei, China. The National Personal Transportation Study (NPTS) revealed 10.3% of those living within 1/4 mile of public transit used it to get to work, while only 3.8% of those living between 1/4 and 2 miles used it, and less than 1% of those living farther away than 2 miles used it (U.S.DOT, 1986). Neilson and Fowler (1972) also verified a strong relationship between walking distance and transit use finding that among adults, transit use dropped by almost 70 percent as walking distance increased from 200 m to 400 m. Several other studies have proposed numerical estimates for ideal transit access distances. Generally, the suggested distance between a potential transit rider and a transit stop is less than one kilometre. For example, Unterman (1990) found 70% of Americans will walk 500 feet for normal daily trips on public transit, while 40% are willing to walk 1,000 feet (1/5 mile), and 10% will walk a half mile.

2.5. Explanatory Factors of Transit Availability

For services to operate in the most efficient way, transit supply, is typically directed to areas characterized by populous spatial or socio-economic traits representative of typical transit users. For example, in terms of increasing or improving services, it is beneficial to focus transit supply to persons residing in geographical areas that are prone or could be convinced to use public transportation. Rural areas, characterized by low population density are a difficult focal point for the provision of transit service, whereas, high density urban areas are key candidates for intensive transit supplies. Understanding the factors which influence where levels of transit supply should be directed is an important exercise for creating and supporting sustainable transportation practices.

In an attempt to evaluate intra-urban transit intensity, previous efforts utilized various spatial and socio-economic characteristics of the population as explanatory factors. Taylor and Fink (2003) reviewed literature concerned with variables which directly or indirectly measure public transit accessibility. Overall, their findings suggest automobile access as the strongest indicator of variation in transit ridership. Economic factors observed as influential to transit ridership included, unemployment levels and income, while spatial factors highlighted population and employment densities, and parking availability. Cervero (2008) employed a nested logit model to estimate the probability someone would reside near a rail station and in turn commute by rail transit in the San Francisco area. Results showed interdependence between transit-oriented tenancy and rail commuting. Socio-economic indicators used in the model confirmed low income, low car ownership, and Asian-American and Hispanic race were associated with residential proximity to transit services. Further examples of studies which have attempted to discern relationships between socio-economic factors and transit use and supply include Morris (1981), Starrs and Perrins (1989), and Syed and Khan (2000). Most of the existing studies make use of the ordinary least square (OLS) regression model to establish a statistical relationship between transit availability and usage and socio-economic and demographic factors. For the purposes of this study, five variables were investigated. Each of the chosen variables has previously shown an established relationship to transit service.

2.5.1. Population Density

Studies indicate that population density is one of the strongest variables used to explain transit usage. A strong relationship exists between residential density and transit service availability, thus, often transit services concentrate routes in downtown urban areas where population densities are typically highest. Ross and Dunning (1997) quantified the relationship through an examination of the 1995 Nationwide Personal Transportation Survey (NPTS), shown in Table 2.1.

Table 2.1 Transit Availability by Population Density (Ross and Dunning, 1997)

People per Mile^2	% Persons with Available Bus Service
0 – 249	20.1
250 – 999	41.0
1,000 – 3,999	69.4
4,000 – 9,999	88.8
10,000 & up	98.0

The findings suggest a significant increase of available bus service with an increase in population per square mile.

2.5.2. Income

The relationship of transit usage and average household income has been explored through the general postulation that people with lower incomes make more public transit trips than people which can afford the expense of the private automobile. This rationalization is verified by Guliano (2001) who acknowledged poor individuals are more likely to utilize transit for daily trips than those of mid to high income ranges. Gomez-Ibanez (1996) established that each percentage increase in real per capita income was associated with a ridership decline of 0.7% in Boston MA. Heisz and Schellenberg (2004) deciphered the relationship of income classifications to public transit ridership as a means of commuting to work in Toronto. The study found a considerable decrease in public transit use, with the increase of average family income. Furthermore, the association between high car ownership and high incomes has been extensively investigated (see: Gray et al. 2001, Deka 2002, van de Coevering and Schwanen 2006). The strong relationship between high incomes and increased levels of car ownership, leads to the complementary relationship between low incomes and high public transit usage (Preston, 2001).

2.5.3. Age

Prior research demonstrates transit use is also related to age. Children and the elderly are more likely to use transit than adults under the age of 65 (Pucher, Evans, and Wenger, 1998). The elderly typically are faced with mobility restriction in terms of their diminishing ability to navigate personal vehicles to their destinations of choice. Thus, the majority of daily activities are dependent on the accessibility and reliability of public transportation. Ashford and Holloway (1972) indicated that the elderly can exhibit a high demand for mobility. Consequently, trip generation rates for elderly persons were found to be similar in general magnitude to those of other adults. Golob and Hensher (2007) supported findings that the elderly rely more on public transit than other age groups; however, it was also clear that young age groups are also high users of public transit. Several million young people use public transport for their school journeys and social activities. At a young age, lack of income may cause a continual usage of transit, unless enabled to assume the expenses incurred with owning a car. Recent research shows that 30 per cent of all young people 15-20 travel by bus (The National Youth Agency, 2007). Heisz and Schellenberg, (2004), found in the city of Toronto, public transit ridership as a means of commuting to work was highest amongst a 15 – 29 year age bracket.

2.5.4. Recent Immigrants

Existing studies suggest a strong relationship between transit usage and the number of recent immigrants residing a serviced area. Heisz and Schellenberg (2004) note the propensity to use public transit for the work commute is far higher among recent immigrants than Canadian-born individuals. Furthermore, immigrants who have resided in Canada for more than 20 years, use transit at the same rate as Canadian-born persons. In Toronto 36.3 percent of recent immigrants, compared to 20.7 percent of Canadian-born persons usually commute by public transit (Heisz and Schellenberg, 2004). Myers (1996) found recent immigrants in southern California were far more likely to use public transit than native-born people. Between 1980 and 1990, forty-two percent of all transit commuters were recent immigrants. Both Heisz and Schellenberg, and Meyers defined a "recent immigrant" as a person arriving in the area within the last ten years.

2.6. Summary

This chapter has provided a brief overview of the previous research efforts and factors pertaining to the investigations presented in the following chapters. Although currently in North America, there is a high preference for private vehicle use as opposed to public transit services, the literature suggests transportation services characterized by an acceptable level of convenience and availability may effectively increase ridership levels. Policies promoting smart growth development; which may be characterized by the integration of transportation and land development, and provision of highly accessible, reliable, affordable public transit services, are strategies recognized to encourage modal shifts. The literature points to two streams of research; the investigation of transit demand potential within given areas, and the measurement of existing transit service availability. The second research focus indicates previous studies have implemented strategies for measurement using tools designed to measure partial aspects of a system, such as individual bus line availability, or a specific destination determination of availability. Furthermore, several studies have used a spatial measure of availability without consideration for the characteristics of the transit systems, such as bus frequencies or capacities. The LITA index is recognized as a comprehensive measurement tool enhanced by the ability to assess transit intensity at several spatial levels for which data are available and display results using GIS technology.

In the chapters which follow the LITA index (Rood, 1998) will be employed for the GTHA using a three component computational process to indicate transit availability levels. Frequency of service, coverage intensity, and transit capacity are all factors documented as highly related to transit usage and indication of service levels. Furthermore, given the findings in the literature, five variables have been validated for use in a multivariate approach to decipher the relationship of transit availability to recognized spatial and socio-economic indicators of the general population in the study area.

CHAPTER THREE: Assessing Transit Availability Levels

3.1. Introduction

To encourage and sustain transit ridership, agencies must provide a service which meets the travel needs of the desired audience. Transit availability is a fundamental factor which can greatly influence an individual's modal choice decision for their weekday travel needs. As captured in the review of the literature, assessment of transit availability at an appropriate spatial scale can be an extremely valuable tool to transit agencies and municipal planners endeavouring to design policies to increase transit ridership and implement smart growth development strategies. The purpose of this chapter is to assess transit service levels within each of the designated study areas. This chapter begins with an overview of the selected study area and data requirements for this research. The methodology employed for the application of the LITA index is then described. Next, the results section proceeds with a general comparison between regions based on the results from each component LITA index. Visual representation of the overall LITA index results and an analysis of the trends and patterns for each of the concerned areas are then discussed. At the conclusion of this chapter there is some final discussion and the intentions of the subsequent chapter are introduced.

3.2. Data and Methodology

3.2.1. Study Area

The region of interest for this thesis encompasses the Greater Toronto and Hamilton Area as shown in Figure 3.1. The study area encompasses a total of 1156 census tracts, which form the units of analysis for this research. The relatively small spatial scale allows for greater data variation to be captured and a more precise system of analysis to be executed.

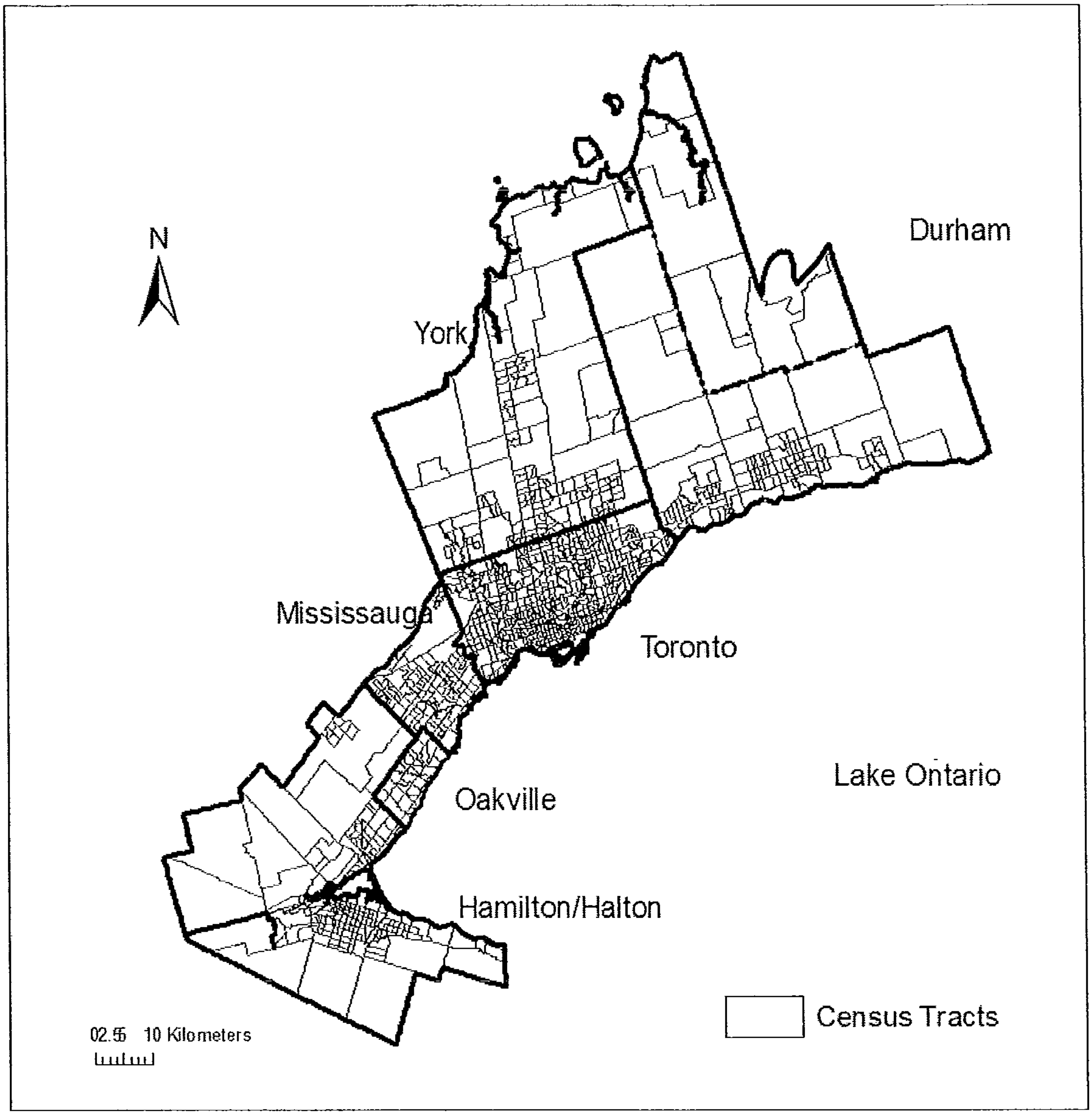

Figure 3.1 The Greater Toronto and Hamilton Area (GTHA)

The GTHA is one of North America's fastest-growing economic regions. It encompasses a work force of approximately 2.9 million people, more than 100,000 companies, and a gross domestic product of U.S $109 billion, making it Canada's business and manufacturing capital (Greater Toronto Marketing Alliance, 2005). The spatial and socio-economic characteristics of the region, in addition to the features of each individual transit system, signified the necessity to calculate transit availability through multiple separately delineated regions. Six areas of analysis were created using municipal boundaries for much of the area delineations. The resulting regions are thus referred to as Durham, York, Toronto, Mississauga, Oakville, and Hamilton/Halton (see Figure 3.1). The region of Hamilton/Halton encompasses the cities of Hamilton, Burlington, and Milton, and includes main service hubs of three transit agencies, whereas the remaining areas typically are concentrated around the operation of one transit agency. The decision to combine the cities in the Hamilton/Halton region into one study area stems from the recognition that a robust analysis would not result from the investigation of Milton and Burlington as separate study areas due to the small number of census tracts and transit coverage.

3.2.2. Data Acquisition and Preparation

Firstly, a suitable GIS based database was assembled. Bus stop and routing shapefiles were acquired from the Municipalities of York, Region of Durham, Cities of Hamilton and Burlington and the Town of Milton. Shapefiles of transit stops were acquired from the Town of Oakville and Mississauga Transit. The Toronto Transit Commission (TTC) supplied routing shapefiles. The assembled data were organized as a

GIS database within ArcMap v. 9.3. GIS programs have been extensively used in studies of this nature (see for example: Grengs 2001, Yao 2007, Gebeyehu and Shin-ei Takano 2008). The acquired stop and route shapefiles were compiled and combined with an Ontario land use file depicting the boundaries of each census tract, taken from 2007 DMTI CanMap data. DMTI CanMap data was also utilized for the designation of land-use classifications. Supplementary sources of data included bus schedule information downloaded from official online sources pertaining to 2009 schedules. Only schedules, routings, stops and other information that pertained to Monday through Friday transit services were considered. At the spatial resolution of the census tract, Statistics Canada makes available a variety of census data. Various statistics including population and employment sizes were obtained from this source. All census data used in the analysis refer to the year 2006.

Data compilation was slightly more complex for the region of Durham. Statistics Canada does not delineate census tracts in the north-east region of this study area as census tract classifications are only allotted to metropolitan classified areas. Thus, nine areas representative of census tracts were estimated based on dissemination area boundaries for this section of the study region. Data inputs for this area were gathered at the dissemination level, combined, and averaged to estimate statistical information. Furthermore, similar estimations were employed throughout all study regions for any census tract data suppressed by Statistics Canada.

3.2.3. Index Methodologies

The calculation of an overall LITA score is typically a composite of three individual index scores: frequency, capacity and service coverage. Each index is derived based on a computation representative of the index. The components of each index required the compilation of data in spreadsheet format. This data collection resulted in an extremely comprehensive and extensive database of specific transit characteristics applicable to each census tract in the six regions forming the GTHA.

3.2.3.1. Frequency Index

The frequency component of the LITA index is derived from the total number of transit vehicles on all of the route lines in a tract over a twenty-four hour period. The LITA implementation guide suggests the total number of daily buses for each route to enter and stop at least once be tallied. However, this index calculation often merely becomes a function of larger tract sizes achieving a higher frequency score as the more area a tract covers the more likely additional buses will enter the tract. To account for this effect we divided the number of vehicles entering a tract by the developed area of the tract as follows:

$$f_i = \frac{v_i}{a_i}$$

Where f_i is the frequency score in tract *i*, v_i is total daily vehicles entering the tract and a_i is the area of developed land in the tract. This is done for all tracts with transit lines having at least one stop in the tract. The total number of daily vehicles is computed as the total number of buses on each route to enter a census tract *i* and stop at least once over a twenty-four hour period. Land area classifications were made with the following parameters:

- *Developed Land*: commercial, government and institutional, parks and recreational, residential, resource and industrial
- *Undeveloped Land*: water body, open area

3.2.3.2. Capacity Index

The capacity measure for the LITA index uses an assortment of variables to gauge the ability of the transit service to accommodate the population of the tract. The computation of the index is as follows:

$$c_i = \frac{(v_i \times s_i) \times (t_i + 0.5\, r_i)}{P_i + E_i}$$

Where c_i is the capacity score in tract *i*, v_i is total daily vehicles entering the tract, s_i is the capacity (seats) of a transit vehicle entering tract *i*, P_i is the resident population of tract *i* and E_i is the employment of tract *i*. On the other hand, t_i is the length of two-way route completely within tract *i* and r_i is the length of route bordering tract *i*. One way segments were also counted as 50% their actual length. Note that the product $(v_i \times s_i)$ reflects the total number of seats on transit lines servicing tract *i* whereas the summation $(t_i + 0.5\, r_i)$ resembles the total route kilometres of transit lines servicing the tract.

The capacity of transit vehicles was derived from a weighted average of seating capacities for all possible transit vehicles to enter tract *i*. The employment of each tract was derived for every census tract based on 'place of work' census data. Place of work data provides the number of employees working in each tract by type of occupation. A summary of each occupation type per census tract provided an excellent estimate of the distribution of jobs per tract.

3.2.3.3. Coverage Index

The service coverage component is based on the density of transit stops. The route coverage index is a simple ratio calculated as follows:

$$g_i = \frac{o_i + 0.5q_i}{a_i}$$

Where g_i is the coverage score in tract *i*, o_i is number of transit stops completely within tract *i*, q_i is number of transit stops bordering tract *i*, and a_i is the area of developed land in the tract. Stops were counted separately for each transit line following these parameters:

- bus stops on opposite sides of a street at the same intersection are only counted as one stop
- if the block is large enough that vehicles make more than one stop between intersections, each stop is counted separately

3.2.4. Comprehensive Index Evaluation

For every index, the scores of the census tracts are standardized to produce z-scores, thus, enabling a LITA grading scheme to be applied. An overall LITA transit z-score is found by averaging the z-scores from each index computed for the given tract. A comparison between regions via the use of z-scores is justified through the analysis of the distribution of scores for each of the LITA components as shown in Figure 3.2.

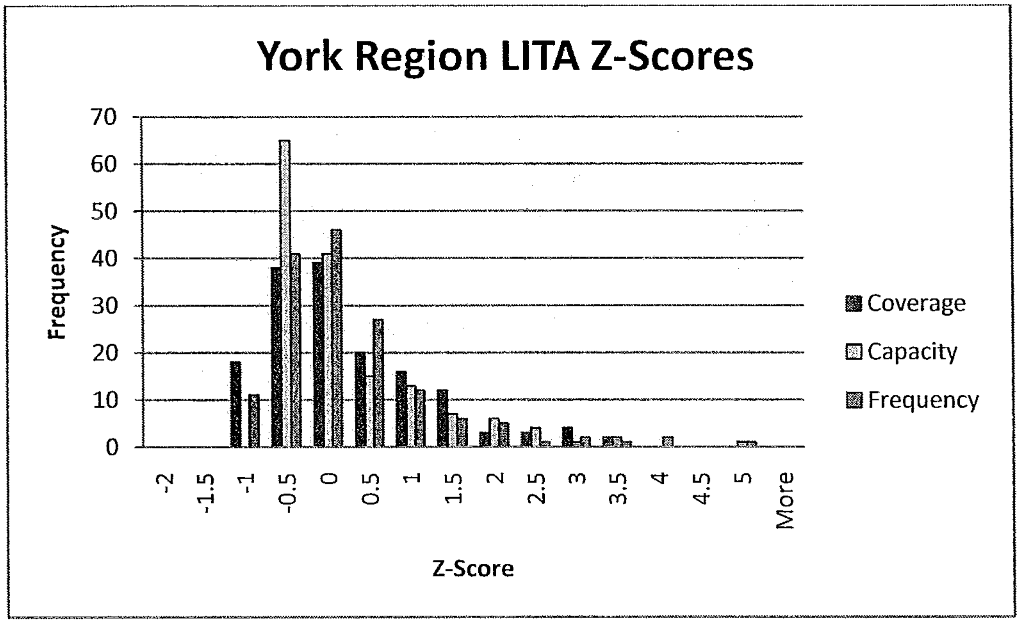

Figure 3.2 York Region Z-scores of LITA Index Components

Figure 3.2 confirms a reasonably similar distribution of z-scores for each LITA component using the York Region data. This indicates that it is acceptable to use z-score standardization to enable an average score to be deciphered between observations from each distribution. A similar analysis was conducted for each of the regional data sets to ensure comparability between scores.

Previous LITA based studies have adjusted the standardized scores by adding a value of '5' to each score, with a purpose of avoiding the use of negative values. An "A" thru "F" grading system is assigned based on these values, with an 'A' representative of excellent transit availability, and subsequent grade assignments are assessed to tracts as service intensity levels decrease. For the purposes of this research, this scoring system was deemed inappropriate. A chief deterrent of this grading system stems from the use of the arbitrary value of '5' to generate positive scores. Using the data generated by this study, such a grading system would result in an inaccurate intermittent assignment of a 'D' grade, to tracts with no transit service, which is clearly a misrepresentation. Furthermore, several regions, dependent on the spread of the data, would show a dominance of C grade classifications (average transit availability) and very few low or high range graded tracts. Since the main focus of this study is to ascertain the locations of very high or low areas of transit, the conventional LITA implementation grade scheme was deemed unusable.

Thus, a new classification scheme was implemented for the standardized z-scores. A ranked percentile scheme was employed to categorize levels of transit. For each region, the total number of scores was divided into five quintiles (20% of total scores in each group). Each 20% quintile was assigned a level. Level 1 represents the lowest 20 percentile of scores; level 2 is associated with the 20-40 percentile range and so on, to level 5 which represent the top 20% of the scores. Very broadly, the association of the levels for the designated regions are as follows:

Level 1 – No service or extremely limited availability

Level 2 – sparse to less than average levels of availability

Level 3 – average levels of availability

Level 4 – average to good levels of availability

Level 5 – excellent levels of availability, best in region

Our method of classification is an improvement to the index as it creates a universal template for the LITA index, indicating this scoring system is appropriate to be applied to any region, and will guarantee a five level spread of service analysis.

3.3. Results and Discussion

Each of the regions in the study area includes at least one census tract which has no provision of transit service. The region of Hamilton/Halton encompasses the greatest number of transit deficient tracts with seventeen. Conversely, only one tract in the region of Mississauga lacks transit services. Data availability allowed for capacity score calculations for three of the regions, coverage index score calculations for five of the regions, and frequency score computations for all six regions in the study area. It is important to note that scores in each study region are derived based on the transit characteristics of that region only; therefore, assigned levels of service availability may not share the quantitative characteristics of like graded tracts in another region. Level assignments simply indicate the transit service intensity of a tract in comparison to all other tracts of that specific region.

3.3.1. Regional Comparisons

Completion of the LITA index calculations enabled a general comparison between the levels of service characterized for each of the study areas investigated. The capacity index results indicated the transit services in York region offer significantly higher capacity levels than Hamilton/Halton or Durham Region. The average total daily seats available per kilometre of transit lines in a census tract once divided by the tract population (refer to section 3.2.3.2. of this chapter), was 18.1 for York Region. Durham Region averaged 6.8 seats while Hamilton/Halton averaged 8.7 seats.

In terms of coverage, the Hamilton/Halton Region and Mississauga Region offered the highest average stop densities with approximately 15 stops within each square kilometre of developed land. With the exclusion of the 17 tracts in Hamilton/Halton which receive no service, the coverage level increases to 17 stops per land area, however, the minimum to maximum z-score differential is the largest amongst regions indicating a significant spread of coverage densities. Oakville presented the lowest coverage levels with an average of 10.4 stops per land area.

Furthermore, the results of the frequency index suggest that transit services in the Toronto region operate at least three times as frequent as services in any of the other regions. Overall, 1544 transit vehicles transverse a square kilometre of developed land on average in Toronto over a twenty-four hour period. Toronto also exhibits the greatest variance of frequency index z-scores amongst census tracts. The next most frequent services are offered in the Region of Mississauga with 550 buses per land area. The most infrequent service on average is found in Durham region with an estimation of 120 buses per land area over a one day period.

Tables detailing further information on regionally derived statistics from each of the individual indices can be found in Appendix A, tables A.1, A.2, and A.3.

3.3.2. Region of Hamilton/ Halton

The region of Hamilton/Halton encompasses 188 census tracts and a population of 741,463 persons. Located in the region are three major cities; Hamilton, Burlington, and Milton. A municipal transit service is operated from each of these areas. Burlington also receives a small level of service from Oakville transit. Each of the three LITA component indices was completed for this area. Individual maps depicting the results of each index are found in Appendix A, Figure A.2. The resulting overall transit availability levels are presented in Figure 3.3.

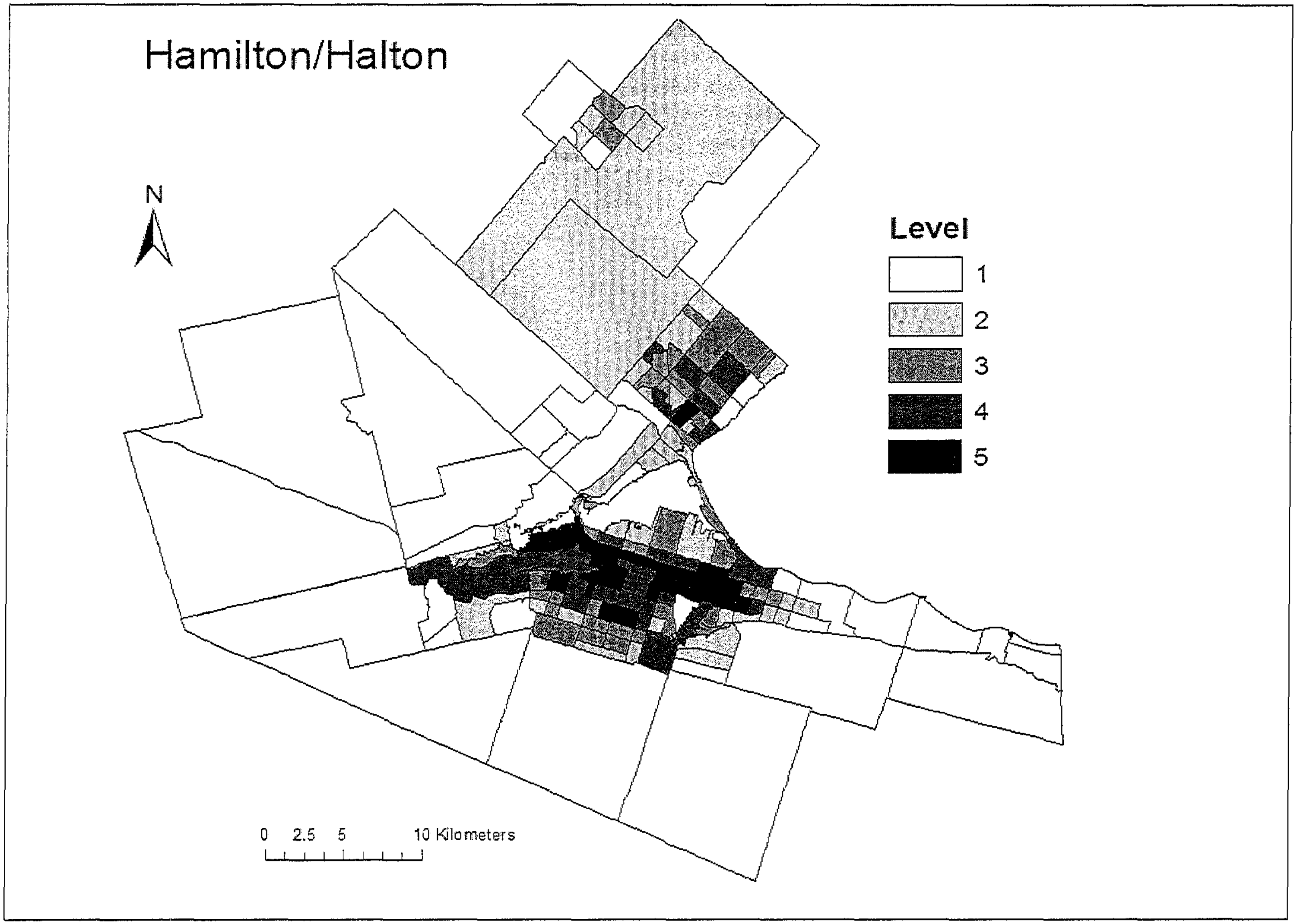

Figure 3.3 Overall Hamilton/Halton LITA Scores

The transit availability scores indicate a dominance of high levels in the urban core of Hamilton. The lowest scores are predominantly assigned to the perimeter area tracts which experience no or very minimal levels of transit service. This region presented the greatest range of data scores amongst all study regions and exhibited a difference of 7.45 between the highest and lowest z-scores. Coverage density values for tracts with access to transit represented a phenomenal range of 0.25 to 247.2 stops per square kilometre of developed land. Bus frequencies ranged from 7 to 5060 buses per land area in a twenty-four hour period.

The City of Burlington contains one tract in the top 20th percentile for overall transit availability. This tract contains the Burlington GO station which also serves as a transfer terminal for six bus routes, and contains transit stops from eight separate routes. In Burlington, coverage and capacity levels of each tract were relatively higher than the scores assessed for frequency of service. This indicates Burlington transit operates bus routes less regularly than other service in the region. A downtown core sample of Burlington tracts suggested an average of 252 buses per twenty-four hour period. Furthermore, the area is characterized by a transit deficiency in the easternmost tracts of the city which form the boundary to the City of Oakville. This is partly attributable to larger tract sizes, and fewer operational routes as compared to the central urban area of the city. Also, two tracts located adjacent to the Lake Ontario waterfront were consistently assessed a low level for each transit index computed. This transit service deficient area is residentially dominant with a combined 2006 census population of 8621 persons. Two transit routes operate within these tracts; however, the quantity of stops, and frequency of service is significantly less compared to services of alternate routes in the city.

The Milton area, despite being primarily serviced by a much smaller scale transit service, achieved two tracts within a level 3 transit availability grade, while the majority of the remaining tracts registered level 1 and 2. The core six census tracts of the Milton urban area produced reasonable scores within the coverage and capacity indices; however, the limiting factor in the area is the frequency of service. The city of Milton operates a weekday five line transit system providing service from 5:45 a.m. to 8:30 p.m. with headways ranging from ½ hour to 1 hour. A direct result is a poor level of assessment for the area, as other transit lines in the region offer far greater frequencies of service. The coverage index demonstrated the highest level assessments amongst all indices for Milton, as stop densities are not necessarily a function of service hours.

As suggested by the findings for Burlington and Milton, the services of the Hamilton Street Railway are the most comprehensive in the study region. The census tracts in the boundaries of Hamilton characterized the majority of the highest levels of service for each of the index computations. There is a general pattern of decreasing levels of availability as census tracts expand outwards from the downtown urban core where the best levels of service are concentrated. In particular, two adjacent tracts in the downtown region scored exceptionally high amongst all indices. The high level of transit intensity is directly attributable to the location of the Hamilton GO station, a major hub, and the operation of 20 of the 27 total HSR routes which travel through at least one of these tracts daily. These tracts are also relatively small in size, thus when developed area is factored into the frequency and coverage calculations, the resultant estimations are unparalleled. For example, in terms of bus traffic, these tracts receive 1388 and 1588 buses in a twenty-four hour period. However, with the inclusion of the land area divisor the frequency becomes 3967 and 5060 buses respectively. The average number of buses travelling through a transit provided census tract of this study region is 340. The downtown core of Hamilton is characterized by a complete dominance of the highest frequency levels amongst the region. An area of deficiency in Hamilton includes most of the Lake Ontario waterfront tracts. These tracts are serviced by two lines only; however, these tracts also contain some of the highest employment populations in the regions, signifying reconsideration of transit service levels may be a policy suggestion.

In terms of inter-region connectivity, transit connection between the major communities of the study area is poor. Each individual index assessed the gateway tracts between northwest Hamilton and west Burlington as level 1 to 2. There is only one route which makes a direct link between the urban cores of these cities. There is no overlap of services between Milton and any surrounding communities. Furthermore, poor overall service is highly apparent along various tracts adjacent to the lake Ontario shoreline. Within this study region, the total population residing in LITA assessed level 4 and 5 tracts is 248,698 persons. Therefore, 33.5% of the total regional population has access to above average levels of transit services. 10.8% of the total population has no access to public transit.

3.3.3. Region of York

The region of York encompasses 155 census tracts and an approximate population of 892,712 persons. Services from York Region Transit and the Toronto Transit Commission (TTC) operate within this area. An overall assessment of transit availability was computed for this region using results from all three of the LITA indices. The depictions of the individual index computations are located in Appendix A, Figure A.3. The representation of overall transit availability levels is shown in Figure 3.4.

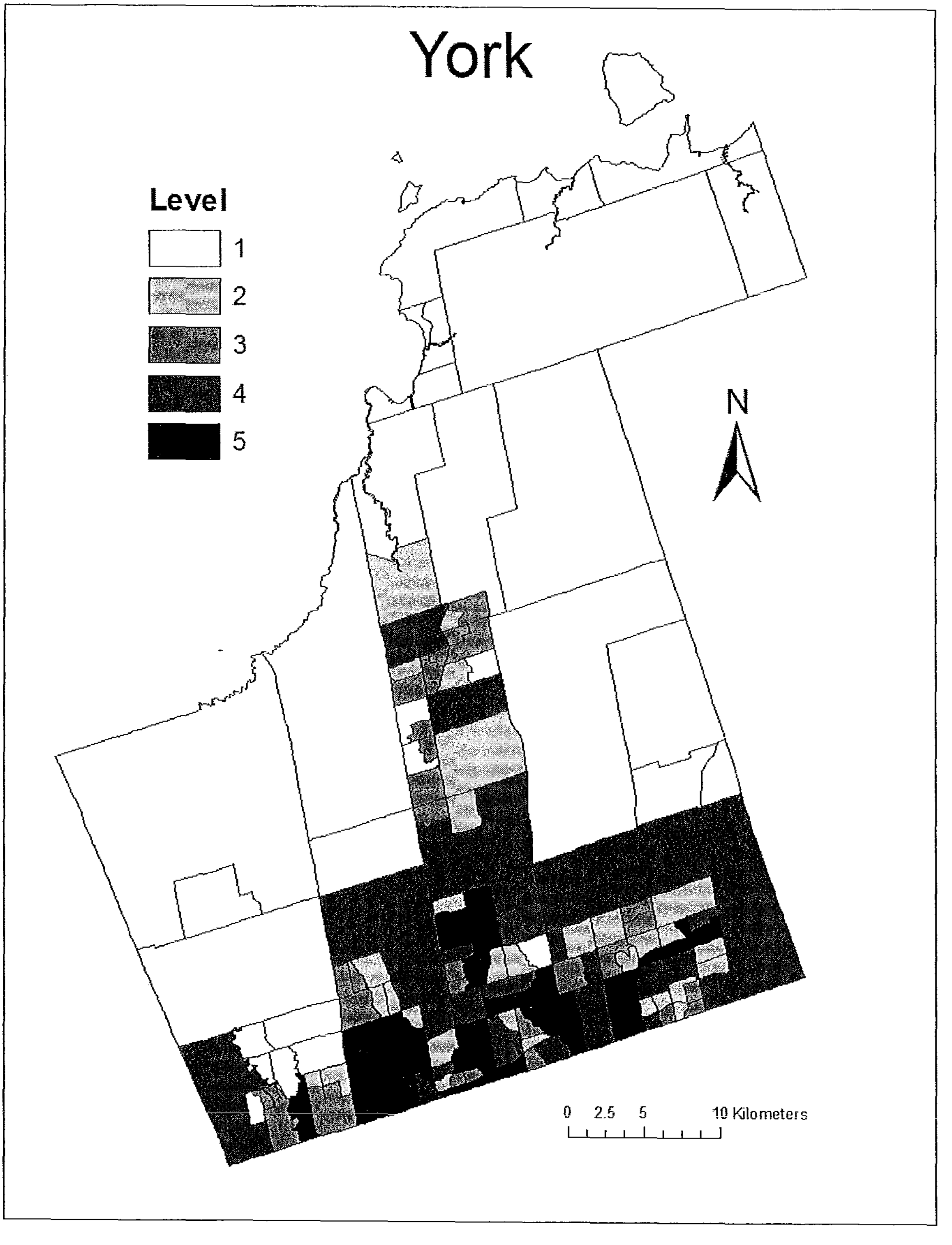

Figure 3.4 York Region Overall LITA Levels

Transit availability assessments in the York region show minimal cohesion between tract levels. Broad patterns indicate the highest ranked tracts are located in the southern vicinity of the region with the higher levels of urbanization. The majority of level 1 tracts are positioned in the peripheries of the region characterized by rural landscapes and low population densities. The data set for York indicates the least variance between scores amongst all regions studied, indicating transit services are offered at fairly consistent levels throughout the region. Level 5 tracts for the frequency index computations indicated an average of 693 buses per day, while the regional average is 279 buses. The average capacity of a transit vehicle operating in York region is 36 seats. Five of the ten highest population density tracts were found to be below average for capacity levels. The average number of bus stops in a tract was 10.9 stops per developed land area.

York region supplies a moderate level of transit service northwards towards the communities of Newmarket, Aurora and Beaverton. Interestingly, the coverage index scores in this area represent a spread of several level 3 through 5 assessed tracts, indicating superior levels of stop densities along transit routes as compared to more highly urbanized areas in the south of the region. A generally lower level of frequent service resulted in overall lower level appraisals for the capacity and frequency indices in this central northern region.

Several level 5 transit availability tracts are situated along the boundary between the City of Toronto and York Region. These tracts typically contain extensions of TTC routes. An increase in the quantity of transit routes in these tracts resulted in excellent capacity and frequency index scores. Another area characterized by excellent service intensity includes tracts in the vicinity of the Richmond Hill GO station (see figure 3.4) where more than 17 separate routes operate throughout. Level 4 and 5 transit availability classifications were assigned to 62 tracts. Based on the cumulative population of these tracts, 38.5% of residents are offered above average levels of transit availability.

Several tracts exhibiting poor levels of transit availability are interspersed through the urban core of the city. As reported in the literature review, population density is typically a large determinant of transit service intensity. However, as shown in figure 3.5, numerous areas with regionally high population densities are subjected to poor transit service levels. Despite a moderate number of buses travelling through these tracts, a low stop density and insufficient transit capacities cause inadequate service levels. Also, there is a relatively large cluster of level 1 and 2 tracts in the western part of the region (see figure 3.4), where population density exceeds 1000 persons per square kilometre. Furthermore, these tracts have a majority land use composition of residential and park and recreation, indicating this area is a candidate for potential strengthening of transit services.

Figure 3.5 Regions of High Population Density and Poor Transit Availability, York Region

3.3.4. Region of Durham

Durham Region is composed of 123 census tracts and an estimated population of 561,286 persons. The sole transit system operating in this area is Durham Region Transit. Durham is composed of four large cities and several small communities. The cities of Ajax, Pickering, Oshawa, and Whitby are aligned along the lakeshore and each contains transit routes which travel within that community specifically as well as routes known as "regional routes" which transverse the east-west corridor of the Durham region. Figure 3.6 depicts a generalized delineation of the major communities contained in the region.

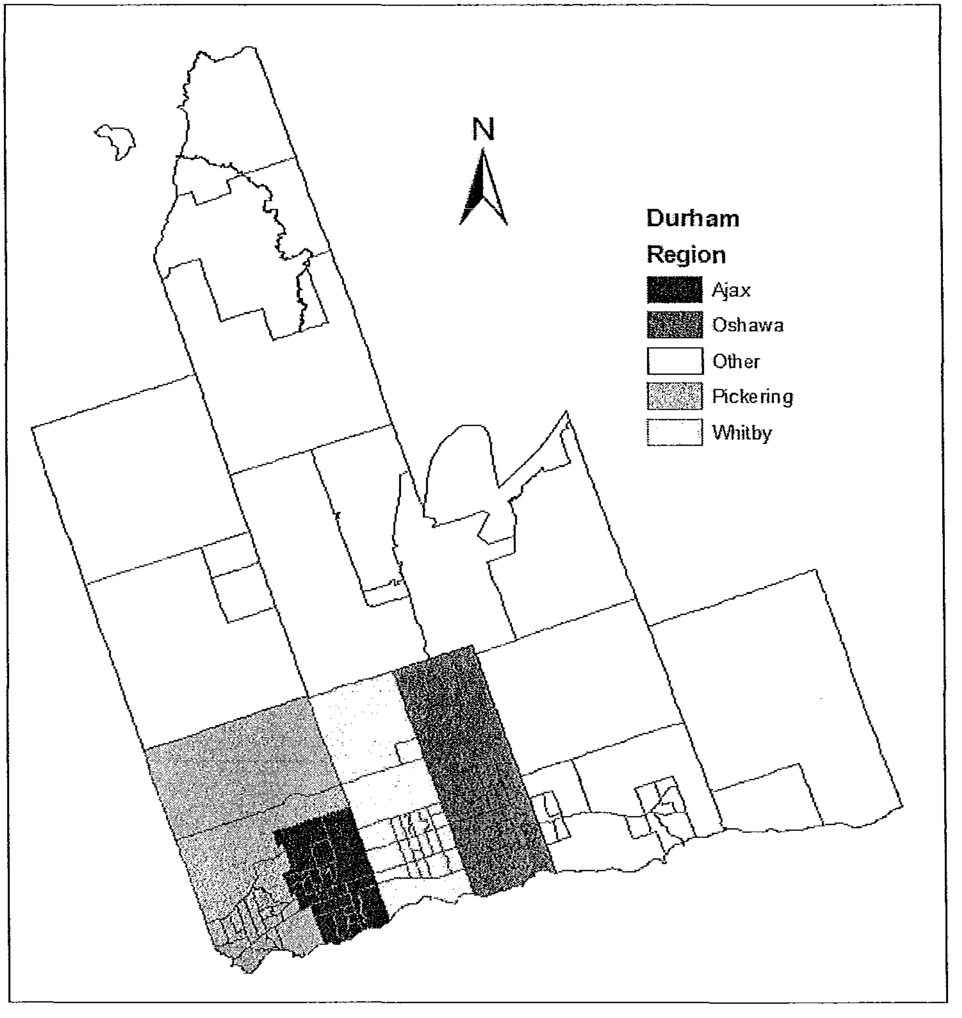

Figure 3.6 Durham Region Major Municipalities

Based on the computations of the three LITA indices, an overall transit availability depiction is presented in Figure 3.7. Results of the individual index computations can be found in Appendix A, Figure 0.3.

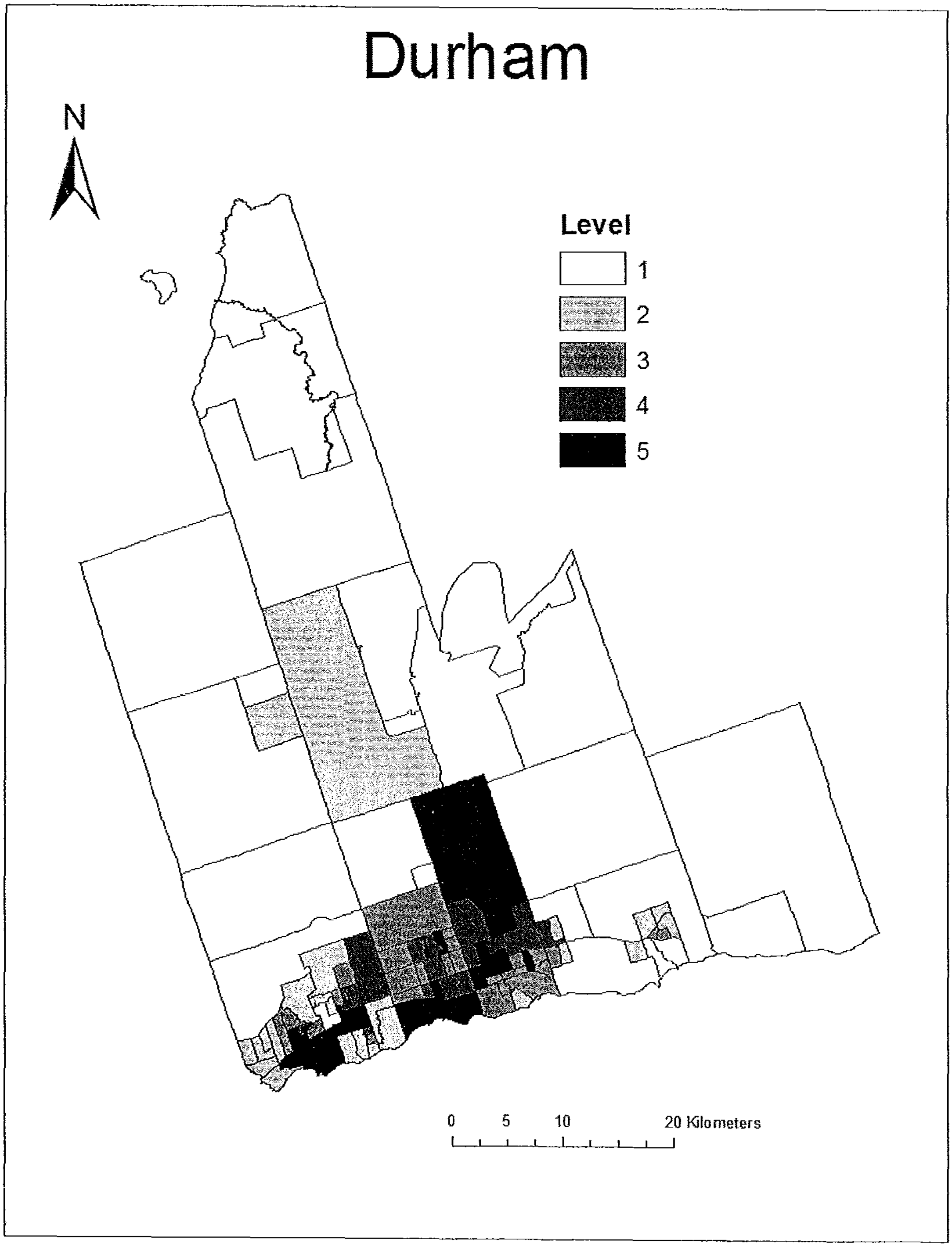

Figure 3.7 Region of Durham Overall LITA Levels

As expected the majority of the highest transit availability is located throughout the urban centres of the four major communities found in the region. Consequently, most all of the level 1 assessed tracts are located in the periphery of the region. Within the boundaries of the four stated communities there is a mixture of availability levels interspersed throughout the tracts. Numerical results of the specific indices highlighted that transit services in general for the Durham Region, are offered at an inferior level to the surrounding regions of York and Toronto, where transit is more intensively operated in terms of frequencies and quantity of routes. Level 5 tracts for the coverage index averaged 32.3 stops per land area with a regional overall average of 13.1 stops. Level 5 tracts for the frequency index averaged 303 buses per day, with a regional average of 120 buses per day. The capacity index indicated the most densely populated tracts in the region were not privy to higher levels of service, as seven of the ten densest tracts were served at average or below capacity levels.

The eastern section of the study area scored very poorly, however, this area is also characterized by relatively low population densities and contains only two small communities which receive transit services; Bowmanville, and Newcastle, Ontario. One tract in the Bowmanville vicinity received a level 3 assessment overall, indicating average range transit intensity. This tract was propelled to this level, mostly through a high coverage index score, and due to the location of a transit hub for connections between four transit lines. Lack of frequent bus services was the chief deterrent of transit availability for the eastern section of the study area.

The northern vicinity of Durham Region is also characterized by rural landscapes and low population density. There are four transit routes which are directed through the core of the area to the northern peripheries. However, due to comparatively limited services, the highest tract assessments derived were level 2.

The nature of the transit system structure in Durham Region characterizes community based circular routes which converge at transit hubs within each of the four major cities. Thus, the tracts containing hubs scored very well within each of the indicator indices. The Whitby GO station, Oshawa Centre, Ajax GO station, and Plaza station are the hubs characterizing the highest scoring tracts. Amongst all the of southern based communities in Durham Region, lakeside tracts did not score well in the frequency or coverage indices, however, moderate to excellent scores were observed for several tracts in the capacity evaluations. Overall, this resulted in a varied spread of transit availabilities adjacent to the lakeshore, with the highest levels reported in the Pickering and Whitby municipal boundaries.

The majority of above average overall scores are located in the municipality of Oshawa. The bulk of tracts in this region scored well amongst all of the individual index computations. The adjacent community of Whitby shows average levels of transit accessibility in the northern section and higher intensity levels proximate to the lakeshore. Capacity and frequency levels were typically average or greater in most tracts contained in the Whitby area, while coverage levels were assessed at a lower range. Several tracts received a level 2 grading, with only one tract garnering a level 5. Thus, it is apparent stop densities in the city of Whitby are comparatively deficient to surrounding communities. The boundary tracts between Oshawa and Whitby are defined by level 3 evaluations, which create a disconnection between the level 4 and 5 grades found at the centre of each community. This indicates diminished levels of transit between the two regions.

The city of Ajax shows generally average or above transit availability levels for most of the census tracts in the centre of the urban boundaries. However, there is a very apparent cluster of level 2 scores along the lakeshore tracts. Pickering, demonstrates a mixed level of transit service, with the south-east corner representative of the strongest transit levels. This is a function of the location of the Pickering GO station. The municipalities of Ajax and Pickering, displayed a varied assortment of capacity scores, and it was determined that comparatively less frequent services are operated in these communities as opposed to Whitby and Oshawa. Furthermore, there were level 1 and 2 tracts for the coverage index which were interspersed among the urbanized core areas of the cities. These results were of interest as each tract of a below average coverage score contains a large portion of commercial and residential land uses and is located alongside various tracts of excellent coverage ratings yet, exhibit a very low stop density for servicing the existing transit routes. There is also a decrease in service intensity near the northern boundary between Ajax and Pickering. Despite high population densities, several tracts have a level 1 or 2 for transit availability, which indicates poor cross-community transit service.

In conclusion, six tracts in the region containing 3.4% of the total regional population have no access to transit services. The combined population of level 4 and 5 assessed tracts indicates that 37.2% of the total population of the region resides in tracts of above average transit service.

3.3.5. City of Oakville

The city of Oakville contains a meagre 34 census tracts, thus resulting in a less comprehensive analysis of the transit service availability. The regional population is 165,177 persons, and the area is serviced by transit lines from Oakville Transit, Burlington Transit, and Mississauga Transit. Transit availability levels for Oakville were surmised through the compilation of scores garnered from the coverage and frequency indices. Depictions of the individual index results are located in Appendix A, Figure 0.4. An overall evaluation of transit levels is presented in Figure 3.8.

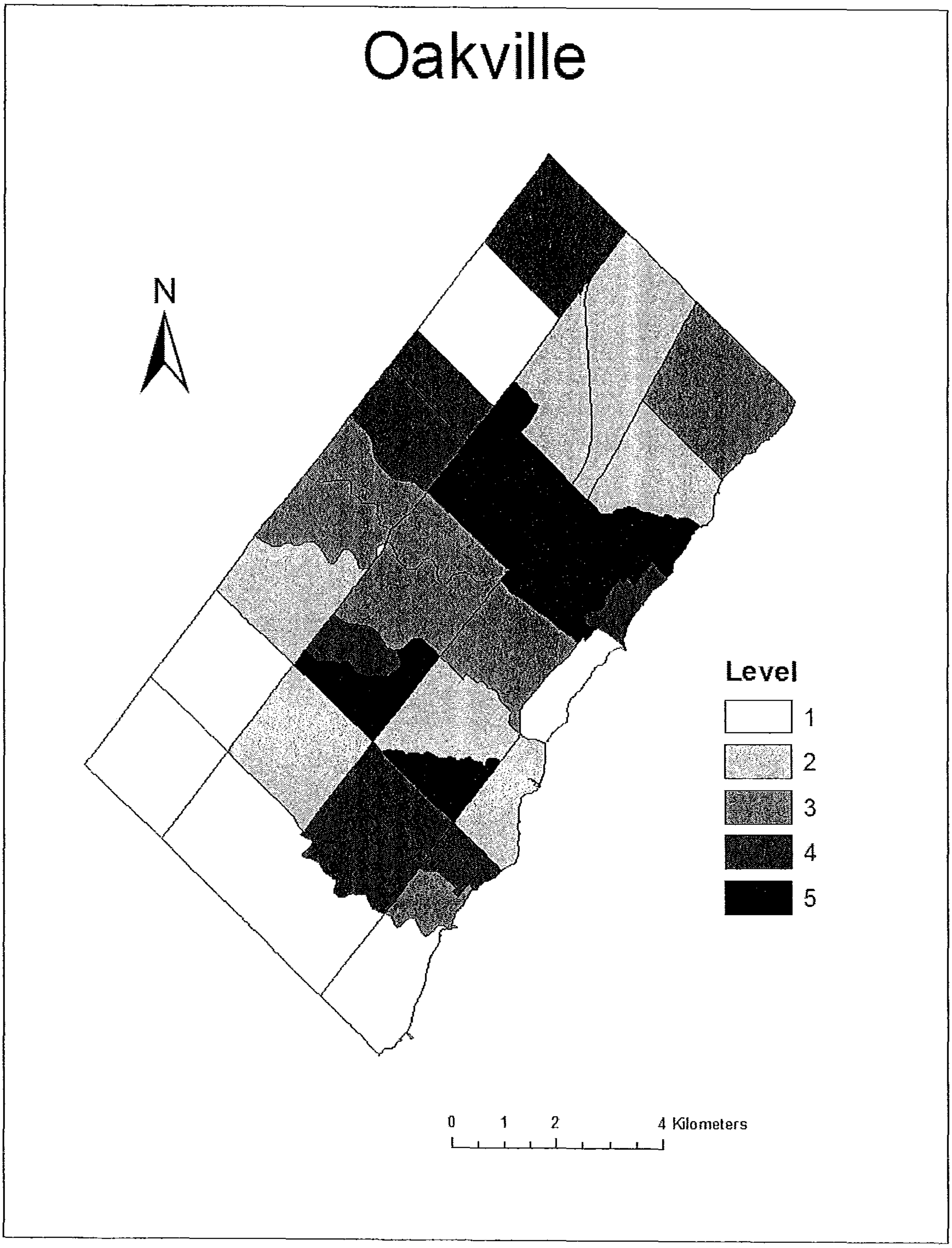

Figure 3.8 City of Oakville Overall LITA Levels

Two tracts in the Oakville study area have no transit service at all, yet 83% and 78% respectively in these tracts is classified as developed land. The majority of the development is defined as 'parks and recreation' (Bronte Creek Provincial Park) yet there is delineation of various residential classifications in each. The computation of stop densities amongst the entire data set ranged from 0 for tracts without service to the maximum 21.4 stops per developed land area. The level 5 tracts presented an average of 17.6 stops per developed land area, while the overall average for the region was 10 stops. The tracts assessed with a level 5 for frequency of services averaged 270 buses per developed land area over twenty-four hours. Level 1 frequency evaluated tracts averaged a mere 28 buses, while the total data set indicated an average of 128 buses travelling through a tract in a given weekday.

Waterfront tracks were characterized by low coverage scores and moderate frequency levels, indicating despite average levels of daily service, there are limited places to board a bus. The highest levels of coverage were spread amongst tracts in the interior of the region, while the highest levels of frequent service were predominantly clustered towards the eastern side of the region.

The overall analysis suggests the greatest overall levels of service availability are located in the central tracts of the region. However, there is a decrease in service between clusters of level 5 assessments at the midpoint of the city. The level 5 tracts in the east of the region contain or are in proximity to the Oakville GO station and Sheridan College, both of which generate considerable transit activity. Similarities between the individual index computations existed in the designation of below average levels of service. Tracts on each perimeter side of the region exhibit poor levels of service. The west side of the region has less bus routes and was consistently assessed a level 1 for service intensity. This indicates there are poor transit service interactions from the City of Oakville to Mississauga and Burlington.

For this region, it was of interest to compare the overall LITA assessment to a representation of population densities. See figure 3.9.

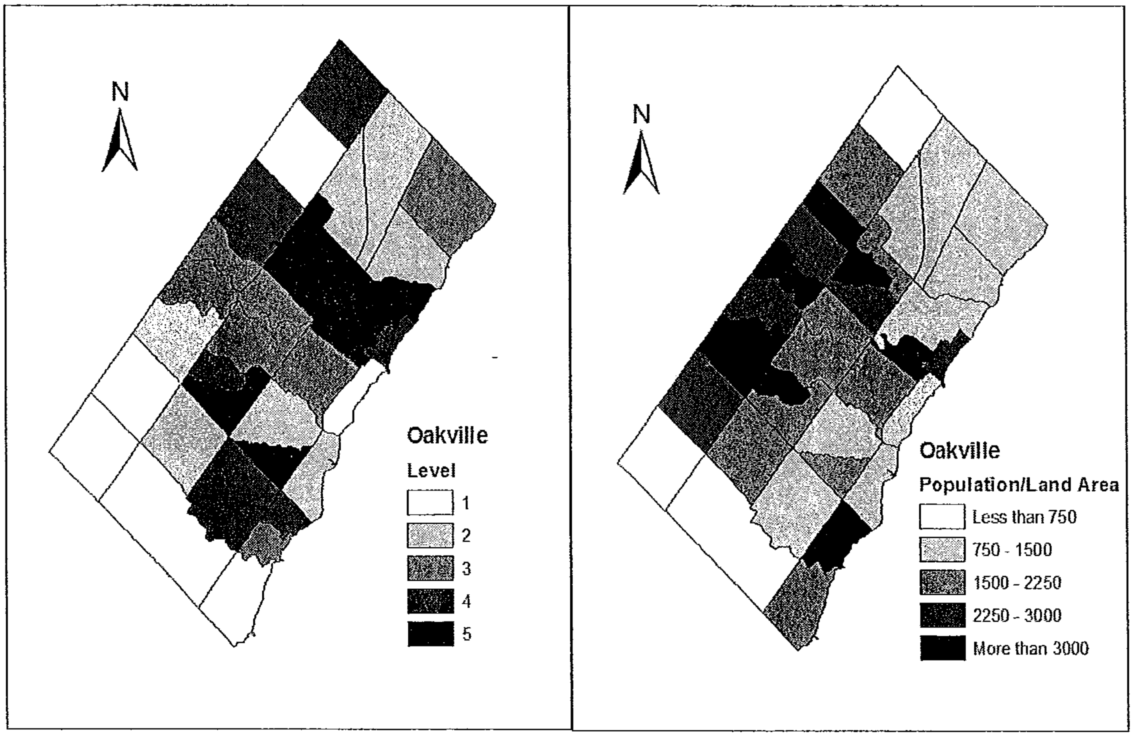

Figure 3.9 Oakville LITA Levels and Population Density

Interestingly, as would normally be expected in a city with an operational transit agency, there is not a strong apparent relationship between the highest levels of transit intensity and the highest concentrations of population density. As indicated, the highest population densities are located mostly along the northwest boundary tracts. Level 2 through 4 assessments characterize the majority of these tracts, whereas the highest levels of service are offered in tracts of moderate regional density.

3.3.6. City of Mississauga

The city of Mississauga is composed of 125 census tracts, and a population of approximately 668,549 persons. Services from Mississauga Transit and the Toronto Transit Commission are offered throughout various tracts. Coverage and frequency index results were compiled to present an overall assessment of transit availability as depicted in Figure 3.10. The individual index map results can be found in Appendix A, Figure 0.5.

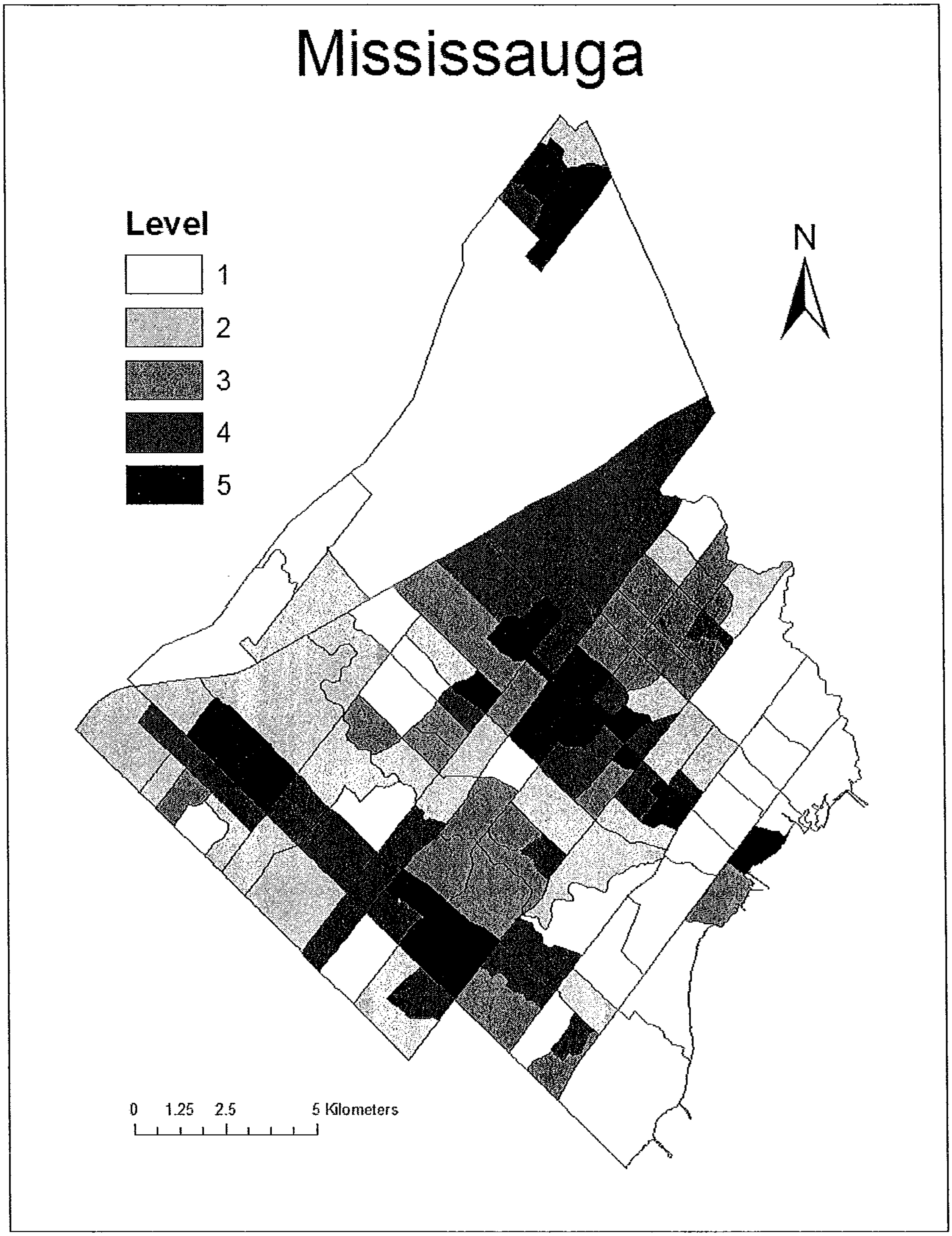

Figure 3.10 City of Mississauga Overall LITA Levels

The coverage index results suggest level 5 tracts average 32.7 stops per land area, with an overall tract average of 15.4 stops. The maximum stop density acquired for a tract was 78.7 stops indicating an extremely high coverage level for tract 5350521.01. This tract is adjacent to a major commercial corridor, proximate to a large shopping mall, and contains a hub for bus transfers. Overall, the average bus frequency per given tract is 550 buses per developed land area over a twenty-four hour period. Level 5 tracts averaged 1363 buses while level 1 tracts exhibit a frequency of 103 buses.

Each of the index results indicated similar areas of superior transit intensity. These areas typically are characterized by the presence of terminal hubs where bus routes coincide to enable transfers, and are often located near large commercial and institutional developments. Examples of these areas are indicated in Figure 3.11. Also, indicated in Figure 3.11 is the sole tract to receive no level of transit service. Interestingly, this tract is categorized as 80% developed land, of which the majority is divided among residential, and parks and recreation classifications.

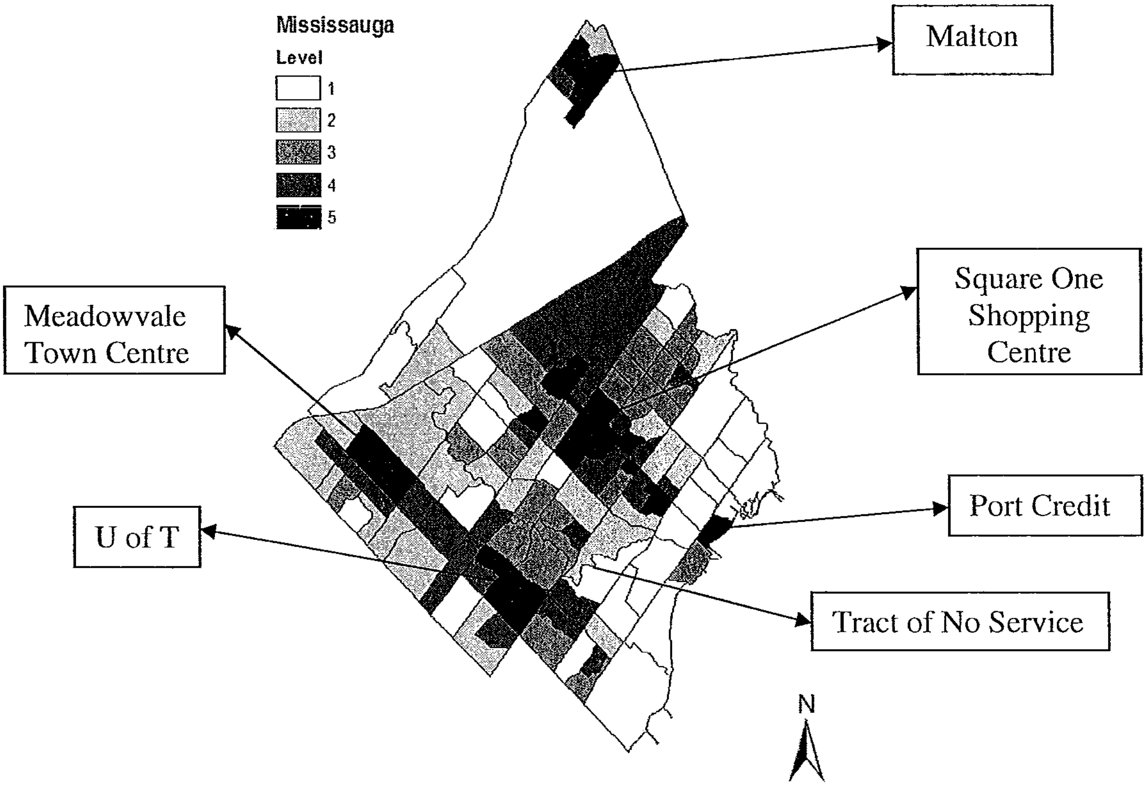

Figure 3.11 Mississauga Areas of Interest

The results of the coverage index computations indicated an extensive stretch of level 1 and 2 tract assessments in close proximity to and along the Lake Ontario shoreline, as well as an indication of very poor coverage in the eastern tracts that create the corridor to the Toronto area. Although, the lakefront tracts did not score well in the frequency index either, generally south-eastern tracts were assessed at a higher coverage level as compared to the frequency scores they garnered. This suggests, despite fewer bus stops, a considerable amount of transit vehicles transverse the area. The opposite pattern is observed in the northern expanse of the area, as service is characterized as dominantly infrequent, albeit a higher level of stop density is present. Despite a general poor assessment for lakeshore tracts, there was a tract which achieved a very high assessment of transit availability. This well serviced tract is the location of 'Port Credit', a water inlet characterized by residential area and tourism (see Figure 3.11).

Another commonality between the index scores, is the intensive level of service offered to the community Malton (see Figure 3.11). This highly residential community characterized by eight core tracts, is situated north of the Pearson International Airport, contains a large amusement park, and is serviced by a TTC route. Despite a geographically significant distance from inner city transit hubs, this community retains a high level of service.

The majority of the remainder peripheral tracts in the region were assessed as level 1 or 2, indicating poor transit interaction with the adjacent cities of Toronto and Oakville. To understand the arrangement of transit service in relation to residential population densities a comparison is drawn in Table 3.1.

Table 3.1 Population Density and Average LITA Grades

Accessibility Level	Average Population Density (persons/square kilometre)
1	2284
2	3311
3	3913
4	4726
5	7626

Indicated by this table, is an increase of density with each increase in transit level. This data verifies the assumption proposed in the literature review, that transit availability has a broad relationship to density of persons residing within a given tract for this region.

3.3.7. City of Toronto

The city of Toronto is the most comprehensive area of analysis in this study, encompassing 531 census tracts and a population of approximately 2,503,281 persons. Transit services from Mississauga Transit, York Region Transit, and the Toronto Transit Commission are employed in this area. The large quantity of census tracts in the Toronto area creates an extremely robust data. Due to data availability, frequency assessment is the sole index computed for the Toronto area. The resultant visual depiction is presented in Figure 3.12.

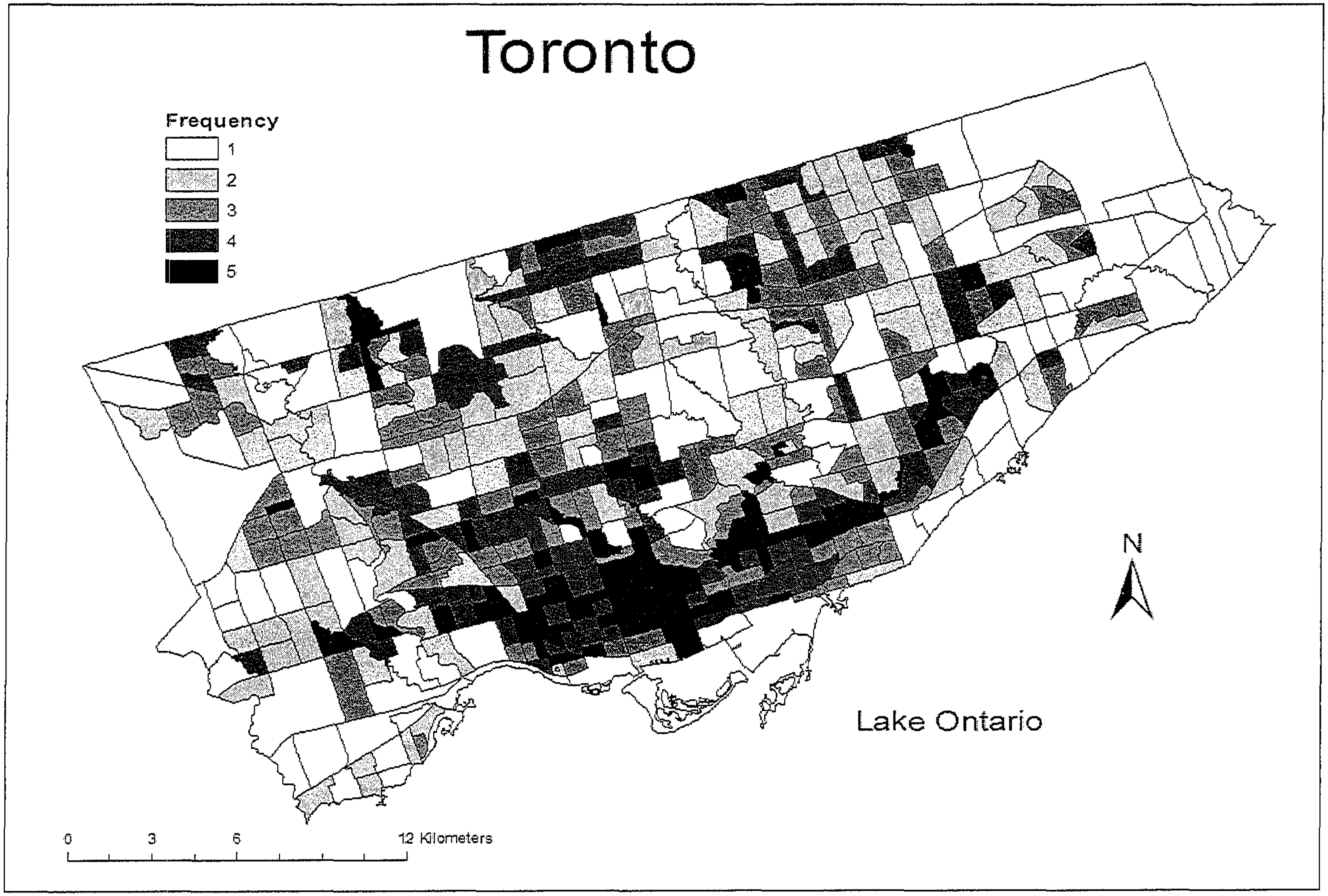

Figure 3.12 Toronto LITA Frequency Index Levels

Toronto is the singular region in the study area to have an included factor of streetcar and subway train services. The average transit frequency per developed land area for all tracts is 1544 vehicles, while level 5 tracts average 3693 vehicles. Before division of the land area factor, the highest actual frequency in a tract was registered as a phenomenal 6668 vehicles. Visual analysis indicates the greatest clustering of high level scores is in the downtown core of the city. As expected, this area is extensively well served, due to the presence of overlapping subway services, and several bus and streetcar hubs. The inclusion of subway service in the region generates tremendous advantages to those residing in tracts encompasses a subway stop. Tracts inclusive of a subway stop averaged 2898 vehicles daily per land area, whereas, tracts with no subway access averaged 1210 vehicles. Consequently, subway services impacted the depiction of levels, as the majority of tracts aligned with a subway stop were assessed as level 5. Refer to Appendix A, Figure 0.6, for a depiction of the TTC subway stops and frequency levels.

Indication of transit interaction with adjacent cities is apparent in the north of the region where numerous tracts are represented by high levels of intensity, suggestive that York region transit services are extending into Toronto. However, lateral interaction of transit service to Durham Region and the City of Mississauga is highly unrepresented as the greatest clustering of infrequently serviced tracts characterize the eastern and western perimeters of the Toronto study area. Interestingly, despite high population density, and intensive urban development, tracts proximate to the waterfront, as a majority, are very infrequently served.

The occurrence of level 1 and 2 graded tracts located amongst areas dominant with high frequency levels may be due in part to the lack of a major road within the given tract. Accordingly, the large collection of poorly serviced tracts in the centre of the region is explained by low population and road densities. Thus, the most prominent indicators of high service frequencies in Toronto are tracts proximity to the downtown urban nucleus of the city, alongside the York Region border, or the tract embodiment of a subway stop location.

3.4. Conclusions

Through the intensive analysis of each index, areas of high and low transit service availability have been identified and partially explained through examination of transit terminal locations, population densities, land-uses and geographical indicators. Trends amongst the study areas include a lack of accessibility along the majority of the Lake Ontario waterfront, increasing service levels towards the core downtowns of each city, deficient service corridors between various communities, and exceptionally high service levels for select few tracts amongst the study regions.

Areas with the highest scores may have the potential (and policy encouragement) for infill development, re-development, and transit oriented new development, whereas areas of lowest scores are candidates for smart growth strategies, improved service planning, and remedial actions. The indication of the level of transit service available at the census tract level provides a basis for city wide assessments of potential public transit expansion or revision. Insufficient transit service can be a key consideration to an individual's modal choice. If people are expected to travel far distances to access transit because the service coverage is lacking, if transit lines offer crowded conditions and are unable to accommodate all passengers, or if long and infrequent headways of a service are consistently offered, alternate transit options are more likely to be utilized by the average individual.

The factors which mold the supply structure of a transit system may differ among cities and transit agencies. The literature suggests that certain socio-economic characteristics are associated with transit use and intensity. The next chapter will strive to verify and/or describe the socio-economic patterns amongst areas of the highest and lowest transit availabilities derived from the LITA index. This will be accomplished through a bivariate and multivariate analysis of the LITA scores determined in this chapter and several selected characteristics of the populations residing in each study area.

CHAPTER FOUR: Modelling Influences of Transit Service Supply

4.1. Introduction

This section of the thesis shifts to a numerical and model based bivariate and multivariate analysis of the transit scores derived and presented in Chapter 3. It is the goal of this chapter to examine indicators of service intensity supply; from a primarily socio-economic perspective. This chapter proceeds with a methodological explanation of the regression modelling approach taken to explain transit service variability. In particular, the importance of the simultaneous auto-regressive model is introduced and explained. A bivariate analysis focusing on the broad relationship between transit supply and per capita modal choice in each tract is the focus of the next section of this chapter. This sets the context for a more in depth examination of transit supply indicators presented in the remainder of the chapter which describes to a comprehensive multivariate analysis. This type of examination is employed using standard ordinary least squares regression models and simultaneous auto-regressive models, and is based on the assumption that no single variable can account for all the variation of transit service availability levels. This chapter concludes with some final remarks and conclusions.

4.2. Methodology

4.2.1. Bivariate Analysis

A simple correlation analysis is performed for each of the regions to test the relationship of transit availability levels and high per capita ridership. Often it is the goal of transit agencies to provide service to areas where several individuals will utilize the services. This research tests this endeavour using work trip data from the 2006 census. This data details the modal choice of residents for their daily commuting needs. The per capita percentage of residents utilizing public transit as their primary mode of transport to work was derived and correlated to the z-score attained from the LITA index within each tract using a standard correlation coefficient analysis.

4.2.2. Multivariate Analysis

A multivariate analysis is performed to identify the factors explaining the variation of transit level of service (i.e. the calculated LITA z-scores). Table 4.1 lists the variables that are introduced as covariates in the analysis. These variables were based on the information gathered from the literature, as discussed in the background section. Specifically, the selection of age groupings for two of the covariates was derived from an overview of previous studies. As stated in the literature review, elderly persons exhibit a high demand for public transit due to their decreased ability to navigate personal vehicles. Most often, the elderly are designated as individuals over the age of 65, thus this served as the basis for one of the age designated variables. The additional age variable which was expressed as individuals between the age of 15 and 30 years was chosen to represent the high demand of younger individuals requiring transit for travel to school and place of employment. Typically, it has been reasoned that public transit use is heightened throughout this age classification as individuals are less likely to have the finances associated with car ownership. Additionally, a number of dummy variables were introduced amongst the covariates to control for observations (i.e. census tracts) with outlier z-scores. These tracts typically represented transit hubs with high traffic, thus, achieve irregularly high availability scores. As such, the dummy variables were expected to be highly significant. Population density, percentage of population over 65, percentage of population between the age of 15-30, and percentage of recent immigrants are hypothesized to have a positive inverse relationship with transit availability, while income is hypothesized to have a negative inverse relationship. A correlation matrix was calculated to test for instances of multicollinearity amongst the utilized variables within each study area.

Table 4.1: Description of Variables used in Multivariate Analysis

Covariate	*Description*
$Popdens_i$	Density of residents per square kilometre in census tract *i*
$Immig_i$	Percentage of total population immigrated to tract *i* in last 10 years (1996-2006)
$Pop15\text{-}30_i$	Percentage of total tract's *i* population in the age of 15 and 30 years old
$Pop65+_i$	Percentage of total tract's *i* population who are older than 65 years
$Income_i$	Average annual income in 2005 of population 15 years and over in tract *i*
Dummy1	1 if tract includes Hamilton downtown bus terminal, 0 otherwise
Dummy2	1 if tract is ID number 5350521.01 in Mississauga, 0 otherwise
Dummy3	1 if tract is ID number 5350528.11 in Mississauga, 0 otherwise
Dummy4	1 If tract is ID number 5350062.01 in downtown Toronto, 0 otherwise
Dumm5	1 If tract is outlier z-score in Toronto, 0 otherwise

Following the existing literature, a multivariate regression model is employed to examine the relationship between transit availability in tract *i* and the variables listed in table 1 for each of the six areas forming the GTHA. The regression equation takes the following form:

$$Y = X\beta + \varepsilon$$

Where Y is a vector reflecting the dependent variable (i.e. LITA z-scores), X is a matrix of covariates associated with the identified independent variables listed in Table 1, β's is a vector of parameters to be estimated and ε is a vector of error terms. Typically, studies assume that the error terms ε_i's are independent and follow the normal distribution. Accordingly, the β's can be estimated via the ordinary least square (OLS) method. The assumption of independence in the error terms can be violated if the data related to the phenomenon under investigation exhibit spatial autocorrelation. The latter may arise if the observed value of a variable in a given tract i is affected by the values of that variable in the tracts neighbouring tract i (Griffith, 2003). The postulation of independently distributed errors is invalid when the response variables are spatially autocorrelated to the dependent variable. The standard errors of the covariates tend not to be conservative suggesting when there is spatial dependence the null hypothesis will more often be falsely rejected.

To account for the effect of spatial autocorrelation, a SAR model can augment the standard linear regression model with an additional coefficient that incorporates the spatial autocorrelation structure of a given data set (Kissling and Carl, 2007). The spatial autocorrelation structure is derived from a 'spatial weights matrix' ***W***, which defines the spatial neighbors that are associated with a given observation (i.e. census tract). For this study, spatial weights were constructed following a 1st order "rook" neighbouring structure. A formal test to explore the existence of spatial autocorrelation can be performed by calculating the *Moran's I* statistic (Anselin et al, 1996). If the latter indicates the existence of spatial dependence in the observed data, the following SAR model can be used to replace the OLS model:

$$Y - X\beta + \rho W(Y - X\beta) + \varepsilon$$

Where $\rho W(Y - X\beta)$ is the additional term capturing the effects of spatial autocorrelation. Furthermore, ρ is the spatial lag parameter to be estimated along with the β parameters. The estimation of the SAR models is performed via the Maximum Likelihood estimation method in the GeoDA 9.5i software package (Anselin et al, 2006).

4.3. Results and Discussion

4.3.1. Bivariate Investigation

From a transit agency or municipal perspective, typically it is of interest to determine if the bulk of ridership is attained in the most highly serviced tracts. A correlation coefficient was calculated for each region between the measured variables of transit availability and per capita transit commuters observed for each tract. Results are presented in table 4.2.

Table 4.2 Public Transit as Modal Choice and Transit Availability Levels

Region	Correlation Coefficient
Hamilton/Halton	0.64
York	0.62
Durham	0.44
Oakville	0.11
Mississauga	0.29
Toronto	0.47

Table 4.2 indicates public transit as a primary modal choice for the work commute does not exhibit a strong relationship to highest levels of service availability in Oakville and Mississauga. This indicates high service intensity is not focused in areas where a high percentage of the tract population is utilizing transit for their commute. Toronto and Durham represent a medium correlation (0.47and 0.44, respectively) between high levels of frequent service and a high percentage of utilization. These values indicate that there is a relationship between high percentages of transit users and service intensity; however, it is only moderate association. Hamilton/Halton and York present the strongest relationships with 0.64 and 0.62 respectively. The stronger relationships found in these regions may be explained by the size of the transit systems. For example, York Region transit and the Hamilton Street Railway serve a significantly larger population, and employ more routes and frequent services than that of Durham Region transit. Thus, the highest LITA level rated tracts within Durham may not actually provide a level of service acceptable to persons wishing to utilize transit for the commute to work.

This may also be a suitable partial explanation for the poor relationship demonstrated in Mississauga and Oakville.

4.3.2 Exploration of Autocorrelation

A *Moran's I* diagnosis test was performed to test the level of spatial autocorrelation using GeoDA (Anselin et al, 2006). Moran's I values were derived from a Moran scatter plot which determined the strength of spatial autocorrelation in the data distribution of z-scores representing transit availability levels. The slope of the scatter plot corresponds to the derived Moran's I value; and is measured at the p-value significance level of 0.001. An exception is Oakville which due to the limited number of observations, was measured at an approximate significance level of 6 %. Results from the Moran's scatter plots are shown in Table 4.3.

Table 4.3 Regional Moran's I Values

Region	Moran's I
Hamilton/Halton	0.5621
Durham	0.4836
York	0.4422
Mississauga	0.3340
Oakville	0.2840
Toronto	0.3801

The resultant positive *Moran's I* values indicate the presence of spatial autocorrelation to different degrees in each of the regions. There is a significant difference between the values derived for each area as Hamilton/Halton produced the highest Moran's statistics while Oakville has the lowest value. Therefore, the application of the SAR model, to control for the effects of spatial autocorrelation is exceptionally suitable for this analysis

4.3.3 Multivariate Investigation

As indicated by the correlation analysis, there are several underlying factors affecting transit supply in the GTHA. Furthermore, from the results of the Moran's I test, it is apparent that there is a presence of spatial autocorrelation amongst the derived transit availability data. Ordinary least squares (OLS) regression and simultaneous auto-regressive (SAR) models were estimated to explain some of the potential factors influencing transit supply. The estimation results for the six regions and two classes of regression models are summarized in Table 4.4. Variable significance was estimated with a beta measure of significance at the 10% level.

While the covariates listed in Table 4.2 were introduced in all models, the $Immig_i$ covariate was dropped from the Mississauga model due to multicollinearity. $Immig_i$ shows a positive high correlation of 0.50 with the density variable $Popdens_i$ and a strong negative association of -0.57 with the income covariate $Income_i$. The results from both the OLS and SAR models indicate that the utilized covariates are able to explain a high percentage of the variability in transit availability. However, the R-squared value rendered from each of the model types is not comparable as the OLS models are estimated via the 'least squares' methodology whereas the SAR models are estimated via the 'maximum likelihood' methodology which results in a pseudo R-squared value.

Table 4.4: Ordinary Least Squares (OLS) Regression and Simultaneous Auto-Regressive (SAR) Model Results

	Hamilton/Halton		Durham		York		Mississauga		Oakville		Toronto	
Covariate	**OLS**	**SAR**	**OLS**	**SAR**	**OLS**	**SAR**	**OLS**	**SAR**	**OLS**	**SAR**	**OLS**	**SAR**
Spatial Lag		0.7331		0.5607		0.6156		0.3341		0.1447		0.5002
		(17.71)		(6.69)		(8.22)		(4.15)		(0.79)		(12.87)
Constant	-0.0564	0.3834	-1.4949	-0.9592	-0.4923	0.4464	-1.8206	-1.1039	-3.7187	-3.4636	-0.9882	-0.4669
	(-0.19)	(1.80)	(-1.32)	(-1.03)	(-1.04)	(1.16)	(-3.53)	(-2.28)	(-3.39)	(-3.48)	(-7.13)	(-3.85)
$Popdens_i$	8.74E-05	-2.64E-05	0.0001	5.47E-05	6.76E-05	2.26E-05	0.0001	9.88E-05	0.0004	0.0004	7.94E-05	5.65E-05
	(4.10)	(-1.70)	(2.65)	(1.21)	(2.64)	(1.09)	(5.78)	(4.83)	(3.29)	(3.28)	(14.30)	(11.21)
$Immig_i$	-0.0199	-0.0104	0.072	0.0606	0.0313	0.0246			-0.0896	-0.0504	-0.0086	-0.0003
	(-1.26)	(-0.94)	(2.18)	(2.22)	(1.22)	(1.18)			(-1.60)	(-1.70)	(-2.95)	(-0.13)
$Pop15\text{-}30_i$	0.1377	0.0068	0.4473	0.2752	0.1062	-0.1859	0.0658	0.0355	0.1745	0.1663	0.0278	0.0038
	(1.16)	(0.08)	(1.22)	(0.91)	(0.55)	(-1.19)	(3.30)	(1.89)	(4.14)	(4.35)	(4.06)	(0.64)
$Pop65+_i$	0.0111	0.0004	0.0528	0.0392	0.0392	0.0242	0.0163	0.0131	0.0442	0.0412	0.0061	0.0075
	(1.90)	(0.09)	(3.47)	(3.08)	(3.64)	(2.76)	(1.52)	(1.34)	(2.56)	(2.64)	(0.57)	(0.81)
$Income_i$	-1.59E-05	-9.50E-06	-1.15E-05	-7.79E-06	-9.91E-06	-1.1391	-7.51E-06	-6.11E-06	-7.48E-06	-7.73E-06	-4.45E-07	-5.67E-07
	(-4.64)	(-3.36)	(-0.89)	(-0.73)	(-2.20)	(-3.10)	(-2.02)	(-1.79)	(-1.17)	(-1.35)	(-0.47)	(-0.70)
Dummy1	6.0391	4.8505										
	(16.19)	(17.91)										

Dummy2							2.9684	3.3317				
							(4.31)	(5.31)				
Dummy3							1.4533	1.7768				
							(2.35)	(3.13)				
Dummy4											6.2763	6.0268
											(9.29)	(10.43)
Dummy5											3.5939	3.5818
											(11.97)	(13.94)
R-squared	0.70	0.85	0.29	0.50	0.19	0.45	0.74	0.77	0.57	0.58	0.59	0.70
Number of Observations	188		123		155		125		34		531	

*Values in parenthesis are t-stat values

For the majority of the regions, the spatial lag parameter was highly significant. The spatial variable was strongest for Hamilton/Halton and Toronto signifying the effects of spatial autocorrelation is intensively present in the structure of transit availability levels for these two regions. When examining the OLS results, the dummy variables were significant in each of the models as expected. The significance of each of the dummy variable used was increased under the conditions of the SAR models.

In the OLS model, population density was significant across all of the study areas, verifying there is a concrete relationship with transit supply intensity. However, it is also recognized that population density may capture some of the same spatial effects as densities of people tend to be clustered over space. Thus, with the introduction of the SAR model, there were substantial effects on the significance of the density variable. In each of the regions, the level of significance decreased and in Durham and York, population density was no longer significant. An extremely unexpected result was the adjustment of the population density variable to a significant negative indicator of high transit supply in the Hamilton/Halton region. This is suggestive of the existence of multicollinearity among the spatial lagged term and population density. Therefore, population density, as in the case of Hamilton, could capture the spatial autocorrelation effects.

Interestingly, a population density t-stat of 11.21 was found for the region of Toronto in the SAR model. This indicates that while the effects of spatial autocorrelation were partially captured by the variable, it still remains a strong indicator of transit service supply. However, previously significant variables from the Toronto OLS model, which included immigration and population over 65, lost significance under the SAR model, leaving only the dummy variables, population density, and the introduced spatial term as significant indicators of high transit supply.

The small Moran's I value computed for Oakville alluded to a limited level of spatial autocorrelation effects. This was confirmed by the spatial lag parameter which was not significant for the Oakville data. Therefore, minimal variation was expected between the results of the two models. Overall, the appraisal of significant variables was slightly altered between the OLS and SAR models as percentage 15 to 30 years, percentage 65 plus, and population density were significant variables in the OLS model while recent immigrants was additionally significant in the SAR model. The OLS regression model explained 58 percent of the relationship to transit availability while the SAR model was able to explain 59 percent of the relationship.

As mentioned, previous studies have suggested that recent immigrants are likely to settle in highly urbanized areas where transit services are most intensively offered. However, immigration was not significant for either model, in any region with the exception of Durham and Oakville. Immigration was significant in both models for Durham, while it became a significant variable in Oakville under the SAR model.

The OLS results suggest in each region, only one of the two age related variables ($Pop15\text{-}30_i$ and $Pop65+_i$) were found to be positively significant with the exception of Oakville where both age classifications were significant variables. Significant age indicators in the OLS models were retained for all regions in the SAR models with the exception of Toronto and Hamilton/Halton, suggesting age does not directly affect transit supply intensities. However, in each case, the significance level for the age variables was reduced in the SAR model results, indicating a mild presence of spatial autocorrelation in these factors. Percentage of residents between the age of 15 and 30 was significant for Mississauga, Oakville and Toronto. This is an interesting result for Oakville as the median age of the population is higher than the provincial average by over two years, indicating transit supply is heightened in the limited areas where young people reside. Percentage of persons 65 plus years of age was a strong explanatory factor for Durham and York. Each of these regions has a relatively young average population age, thus, this result verifies previous findings that transit supply is essential to areas of principally elderly populations.

As hypothesized, income showed a negative relationship to transit availability for each region. However, it was only a significant variable for York, Mississauga, and to a higher degree in the Hamilton/Halton region. Under the SAR model the strength of the t-stat decreased for Hamilton and Mississauga, while York showed an increase in significance of income as a negative indicator of transit intensity. Interestingly, for the majority of the regions, either immigration or income was significant, but not both. This may be a product of an associated between immigration and income levels. Alternately, this may indicate a regional preference to structure transit supply to avoid areas of characteristically low ridership (high income areas), or conversely, focus on intensifying in areas where high ridership may exist (high immigrant populations).

4.4. Conclusions

The goal of this chapter was to model and interpret the relationship of transit availability levels assessed in Chapter 3 to characteristics of the populations residing in the study areas. Correlation analysis of transit availability levels to percentage of transit riders and population density provided a preliminary explanation for transit supply strategy. Transit availability levels showed the strongest correlation to highest percentages of per capita public transit commuters in York and Hamilton/Halton, while the relationship between availability levels and population density was extremely strong in Mississauga and moderate in Toronto and Hamilton/Halton. However, a more comprehensive explanation of transit supply factors was provided through the implementation of SAR models. The utilization of the SAR model proved to be an innovative and essential tool for explaining variable relationships as five of the six study areas indicated significant effects of spatial autocorrelation were at play. The strongest SAR model results were found for Hamilton/Halton and Mississauga where 85% and 77% explanations were produced respectively. Variable significance differed for each region and unexpected results included a negative relationship between transit availability and recent immigration in the Oakville region, and a negative relationship between transit availability and population density in the Hamilton/Halton region under the SAR model.

CHAPTER FIVE: Conclusions

To explore the spatial distribution of transit availability, this study used an extensively compiled database of transit characteristics, to derive a comprehensive measure of transit availability for assessment of service intensity in the Greater Toronto and Hamilton Area (GTHA). The overall robustness of the LITA index was improved through the alteration of the frequency index methodology, and by revising the classification scheme for the achieved scores. Furthermore, five of the six regions investigated showed significant effects of spatial autocorrelation, indicating application of the SAR model was highly suitable and innovative in this research context.

Gauging and measuring the effectiveness of public transportation availability is a tool critical to the evaluation of policy goals and transit planning strategies. Transit availability analysis tools create an opportunity for municipalities to improve transit service while simultaneously constructing policy actions to encourage its use. The integration of land development policies which favour transit oriented development, and increased provision of accessible and reliable public transit services is a key policy action to encourage public transit ridership. Specifically, this research may be considered useful to all municipalities and transit agencies within the GTHA for various reasons. The use of the LITA index has proven to be an effective example of a transit availability tool that could potentially be utilized and recalibrated in this area for transit planning purposes presently and in the future. The tool is successful for providing a visual spatial indication of service supply intensity and structure in the GTHA. Thus, this allows for the opportunity of each municipality to view and assess the current transit characteristics of the area. Secondly, the modelling aspect of this work sheds light on the key socio-economic characteristics serviced by each of the transit operations in the GTHA. This permits additional assessment to determine if potential rider populations are being correctly targeted. Furthermore, the indication of limited municipal transit interaction allows for the communities in the GTHA to observe the potential for increased bi-regional transit relations.

Additionally, the conclusions of this research have many other policy applications. For example, the calculated index may be used by transit agencies to communicate and demonstrate the impacts that changes in funding may have on transit operations and the transit level of service. Additionally, the transit index results provide a supplementary tool to be used in combination with measures that focus mainly on efficiency or performance. Moreover, the modeling results underscore the importance of community assessments when introducing transit nodes and routes. Acknowledging the attributes of frequent transit users allows for service supply to be directed at appropriate intensities per given area. Awareness of relationships between potential transit users and the socio-economic structure of a population is an essential component to transit agencies attempting to increase ridership levels.

It is worth noting that the improvements applied to the LITA index in this study create the potential for several future research initiatives. The index is capable of being applied in several diverse areas, and results provide a reasonable tool for making relative comparisons between urban areas with similar demographic characteristics. Furthermore, assemblage of multiple data sets into a solitary collection allows for the opportunity of provincial or nationwide analysis of transit intensities. Also, this research facilitates further study which may be designed to track changes in transit availability. These results can be used to determine how changing service levels influence residential movement, job opportunity, development patterns, etc.

As is the case with many transit availability measures, there are limitations to the use of the LITA index in this study. Firstly, the use of the census tract as our spatial scale does not allow for detailed analysis of transit intensity in peripheral tracts characterized by large land areas. Thus, it is hard to decipher the concentration of actual transit service. Also, this index takes into account the factors affecting transit availability from the origin of a trip. To decipher if areas targeted for improvement will return increased ridership, investigation of the destinations of trips should potentially also be scrutinized. Lastly, the computation of the LITA index does not take into account the level of pedestrian accessibility to a bus stop. Thus, an area may be evaluated with a high level of transit intensity, however, the walk-ability or access of the region is low resulting in decreased transit use.

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Appendix A

Table A.1 Capacity Index Statistics

Region	Number of tracts	Minimum Z-Score	Maximum Z-Score	Average Total Daily Seats	Average total daily seats* route km / total population
York	155	-0.9598	4.9208	16827	18.1
Durham	123	-0.7993	5.4867	6532	6.8
Halton/Hamilton	188	-0.7627	6.0423	10950	8.7

Table A.2 Coverage Index Statistics

Region	Number of Tracts	Minimum Z-Score	Maximum Z-Score	Average Number of Stops /sq. Km. Developed Land
Mississauga	125	-1.3669	5.6149	15.4
Oakville	34	-1.8644	1.9763	10.4
York	155	-1.4959	3.3357	10.9
Durham	123	-1.0276	5.0704	13.1
Halton/Hamilton	188	-0.5423	8.3506	15.1

Table A.3 Frequency Index Statistics

Region	Number of Tracts	Minimum Z-Score	Maximum Z-Score	Average Bus Frequency /sq. Km land
York	155	-1.0476	4.7609	278
Toronto	531	-1.0699	9.3596	1544
Durham	123	-1.0533	3.0064	120
Oakville	34	-1.4282	2.5357	128
Mississauga	125	-0.8340	6.5694	550
Halton/Hamilton	188	-1.1920	4.9212	310

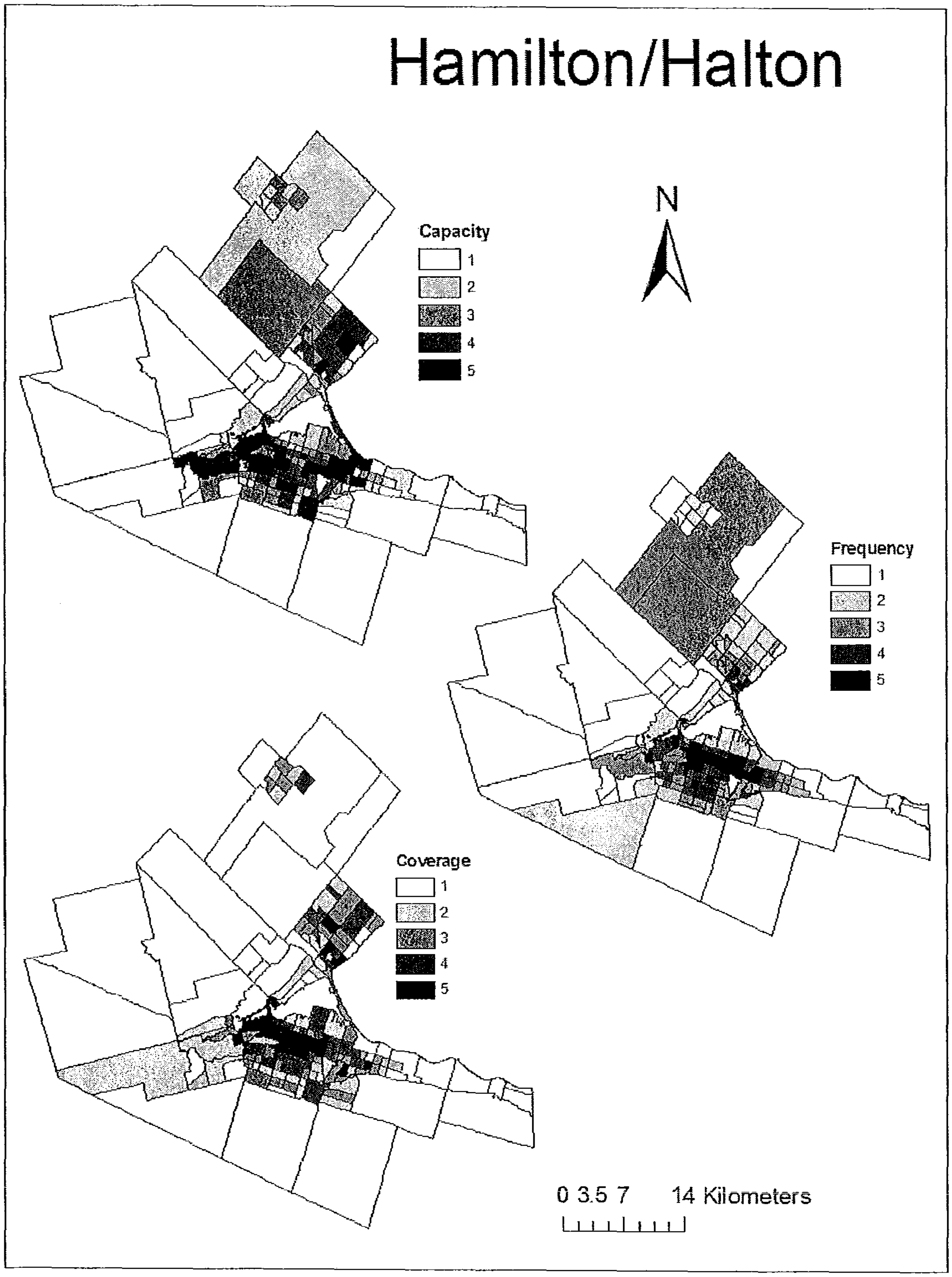

Figure A.1 Hamilton/Halton Individual Index Results

Figure A.2 York Individual Index Results

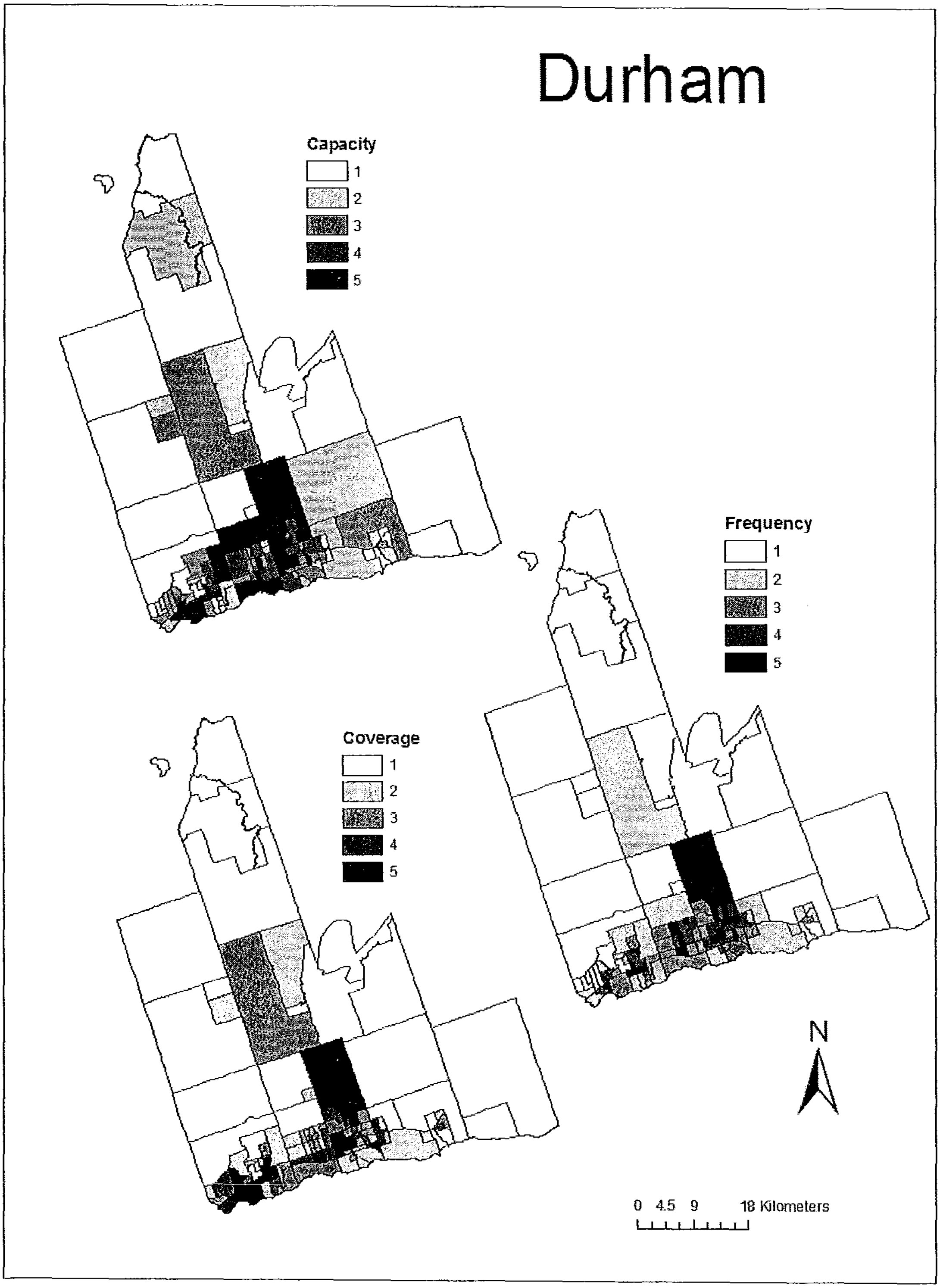

Figure A.3 Durham Individual Index Results

Figure A.4 Mississauga Individual Index Results

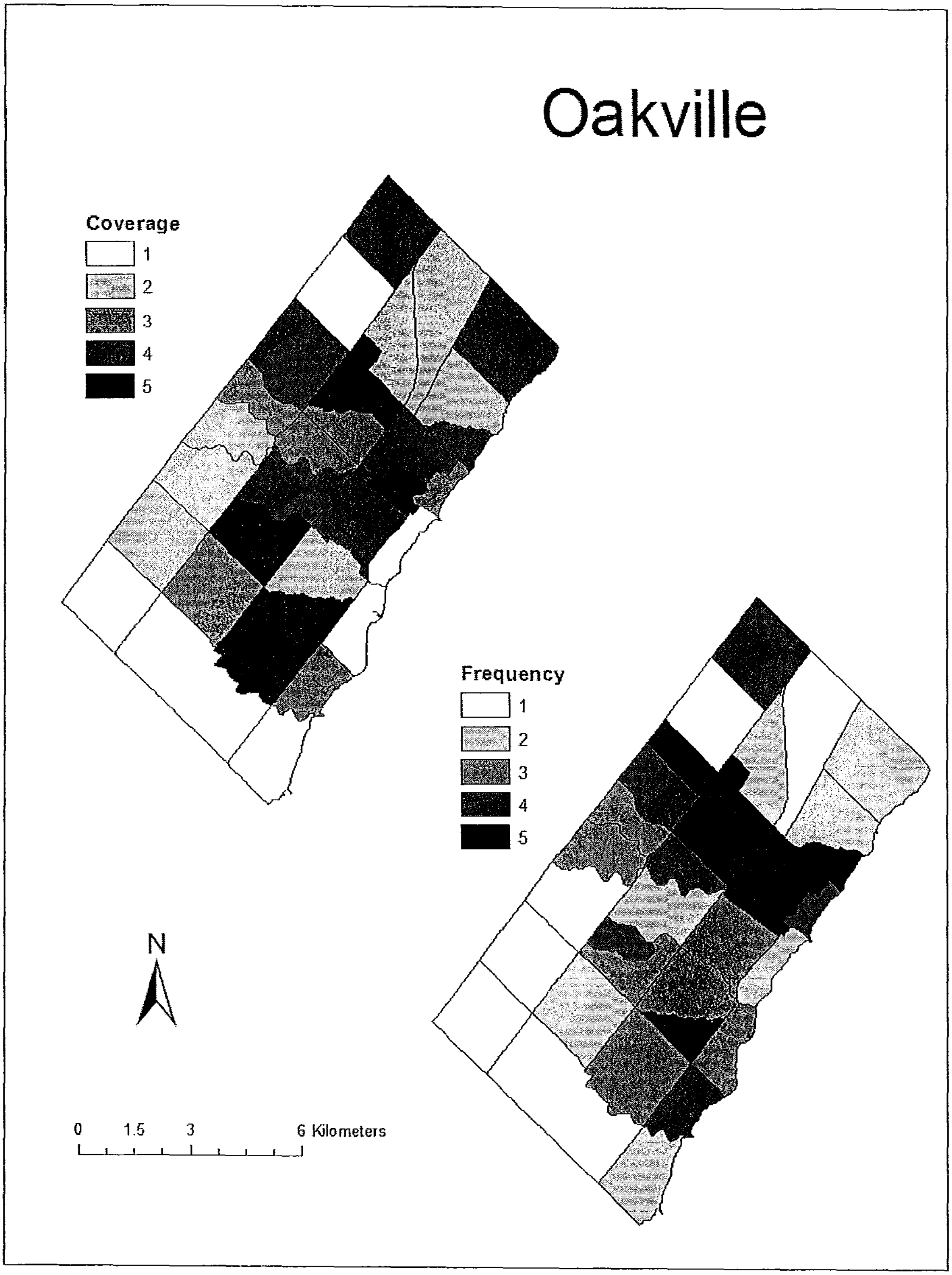

Figure A.5 Oakville Individual Index Results

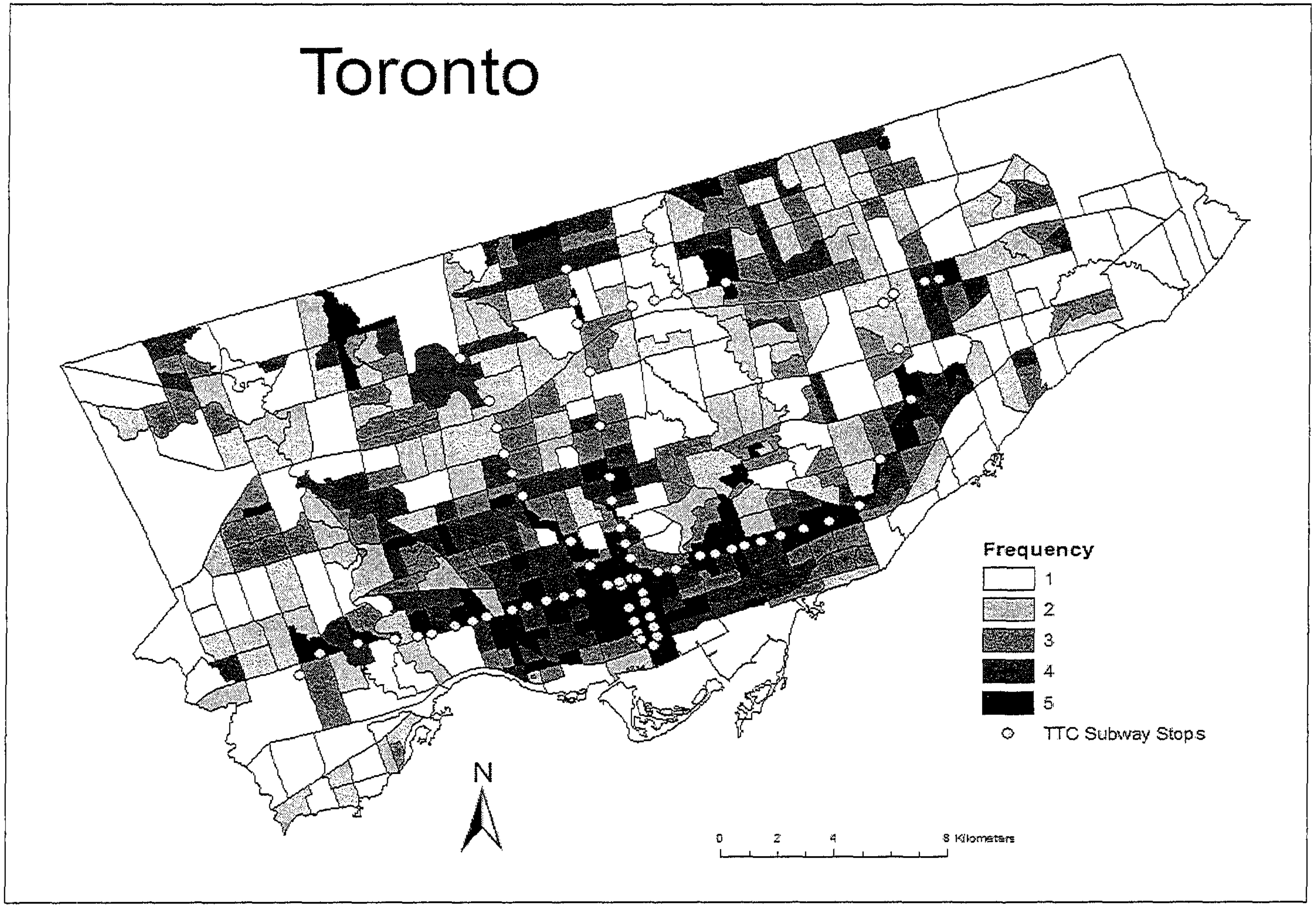

Figure A.6 Toronto TTC Subway Stops and Frequency Index Results