TRANSIT ACCESSIBILITY, SOCIAL EQUITY & JOB TYPE

COMMUTING TO WORK IN TORONTO

1996 & 2006

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SUPERVISED RESEARCH PROJECT

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Transit accessibility, social equity & job type:
Commuting to work in Toronto, 1996 & 2006

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Abstract

This project is presented in two parts as independent, yet related, articles. Part 1 is "Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996-2006". It focuses on how Toronto's transit system serves various socio-demographic groups over time. The location of transit infrastructure distributes publicly-funded benefits to residents throughout a region. However, these benefits are not always distributed equally among different population groups. This research seeks to determine whether the benefits of Toronto's public transit system are equitably distributed, and how these benefits change from 1996 to 2006 after the implementation of several transit projects in the region. The methodology develops a social indicator based on census tract level socio-economic characteristics. This indicator measures the relationship between social disadvantage and accessibility to jobs, as well as transit travel time, in the Toronto region over time. Transit equity is examined at three levels: spatially, temporally, and by job type. Findings show that the range in accessibility and transit travel time narrows over the 10-year period. In addition, the most socially disadvantaged census tracts have statistically significantly better accessibility and lower transit travel times relative to the rest of the region in both 1996 and in 2006. The conclusion is that Toronto has a generally equitable transit system that benefits those in social need, who are likely to gain the most from transit. The methodology proposed presents a useful way to bring issues of social equity directly into the land use and transportation planning process.

Part 2 investigates the influence of job type on commuting in more detail. Part 2 is entitled "Does your job matter? How a changing transport system affects transit mode share among different occupations in Toronto, Canada".

Most mode choice studies aggregate job types when determining commuting travel behaviour, which masks differences in mode choice decisions for different job categories. This study seeks to explain how transit mode share varies by job type, and to assess whether explanatory variables change over time. Using linear regression analysis, Part 2 explores the influence of job accessibility, transport infrastructure, and social disadvantage on transit mode share for three job categories over time in Toronto, Canada, from 1996 to 2006. We find that the aggregate all jobs model dilutes some significant differences between the transit mode choices of job categories, such as for the influence of subway station proximity and accessibility by transit to skills-matched job categories. Further, changes in transit infrastructure over time show that new transit infrastructure does not necessarily attract more transit commuters and it affects job categories differently. Yet, new highway infrastructure hampers transit mode share, regardless of job type. Finally, accessibility by transit increases transit mode share, while more socially disadvantaged areas are more likely to commute by transit in any job category. The conclusion is that job categories should be included in mode share policy and research because aggregating job types diffuses important differences in commuting patterns, and trends over time. These considerations are important for land use and transportation planners trying to boost regional transit ridership and attain social equity goals.

Résumé

Ce projet est composé de deux études connexes réalisées de manière indépendante. La partie 1 s'intitule «Vers un transport collectif équitable : Inspection de l'accessibilité du transport en commun et du besoin social à Toronto, Canada, 1996-2006 ». Cette recherche étudie la manière dont le système de transport collectif de Toronto dessert sa population en fonction des différents groupes socioéconomiques. Cependant, ces services sont rarement distribués équitablement parmi les diverses classes sociales. Cette étude cherche à déterminer si les avantages du système de transport en commun de la Ville Reine sont distribués également ainsi qu'à examiner la manière dont ces avantages ont changé entre 1996 et 2006, suite à de nombreux projets de transport en commun dans la région. Des indicateurs sociaux basés sur les caractéristiques socioéconomiques au niveau des secteurs de recensements sont générés afin de quantifier l'inégalité sociale. La relation entre ces indicateurs et l'accessibilité aux emplois et aussi avec le temps de trajet en transport en commun est mesurée dans le temps. L'équité du transport collectif est examinée à trois niveaux : spatial, temporel et par type d'emploi. Les résultats démontrent que les variations de l'accessibilité et du temps de trajet en transport en commun se resserrent au cours de la période de 10 ans. De plus, les secteurs de recensement les plus socialement désavantagés se trouvent statistiquement avec une meilleure accessibilité et des déplacements plus rapide en transport collectif en 1996 et 2006 relativement au reste de la région. Il est conclu que le transport collectif de Toronto est généralement équitable en avantageant ceux en besoin et qui risquent de profiter le plus du transport en commun. La méthodologie proposée présente une façon utile d'inclure les problématiques de l'équité sociale directement dans le processus de la planification du transport et de l'aménagement du territoire.

La partie 2 enquête sur l'effet du type d'emploi en profondeur. Elle est intitulée « Votre emploi est-il important? Comment la transformation d'un système de transport peut affecter la part modale du transport en commun parmi différentes occupations à Toronto, Canada ».

La majorité des recherches sur les choix modaux regroupent les types d'emplois pour étudier le comportement des voyageurs, cachant ainsi une différence dans le choix modal pour différents types d'emploi. Cette étude vise à expliquer comment la part modale du transport en commun varie par type d'emploi ainsi qu'à évaluer si les facteurs explicatifs changent dans le temps. Une régression linéaire explore l'effet de l'accessibilité aux emplois, de l'infrastructure routière et des inégalités sociales sur la part modale du transport collectif pour trois types d'emplois à Toronto, Canada, entre 1996 et 2006. Nous découvrons que la proximité de stations de métro ainsi que l'accessibilité par transport en commun aux emplois correspondant aux compétences ont des effets sur le choix modal du transport en commun. Ces effets sont significativement différents pour chaque type d'emploi, une différence que le modèle emplois regroupés ne peut saisir. De plus, des changements dans l'infrastructure de transport collectif n'attirent pas nécessairement plus d'utilisateurs, un phénomène qui varie selon la catégorie d'emploi, tandis que l'ajout d'autoroute nuit à la part modal du transport en commun, pour tout type d'emploi. Finalement, une meilleure accessibilité en transport en commun augmente sa part modale alors que les régions socialement désavantagées sont plus enclines à se déplacer avec ce mode, tous types d'emploi

confondus. Nous concluons que le type d'emploi doit être inclus dans les politiques et dans la recherche sur les choix modaux, puisque la combinaison des différents types d'emplois amène à ignorer certaines différences dans le comportement et dans les tendances à long terme. Il est nécessaire pour les urbanistes et planificateurs de transport de considérer ces facteurs afin d'augmenter la part modale du transport en commun ainsi que d'atteindre des objectifs d'équité sociale.

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PART 1

TOWARDS EQUITABLE TRANSIT:

EXAMINING TRANSIT ACCESSIBILITY & SOCIAL NEED IN TORONTO, CANADA, 1996-2006

1. Introduction

Cities are constantly changing.[1] Transportation networks develop, land-use patterns shift, neighbourhoods transform, and residents relocate. New public transit infrastructure or services can have profound and long-lasting effects on neighbourhoods. The positive impacts of new transit infrastructure have been well established: better quality of life (Michalos and Zumbo, 1999), environmental, health, and activity patterns (Wilkinson and Marmot, 2003), and greater accessibility and social inclusion, particularly for those without a car (Grengs, 2001; Lucas, 2006). But, due to the location of public transit infrastructure, spatial patterns of land use, and the locations of different population groups, a key question is raised: who benefits from these changes in land use and transportation? To answer this question, transportation planners must understand the spatial distribution of new transit service and the populations being served.

In recent years, many researchers have started to examine explicitly the role that public transport plays in providing mobility and accessibility to those without other options. Hine and Mitchell find that "transport policy has been shaped by the notion of a universal disembodied subject which has been aided by the reluctance of transport policy to include a social agenda" (Hine and Mitchell, 2001 p. 319). Analyzing benefits by stratified socio-economic groups is one way to address this. Greater attention to transit accessibility for socio-economically disadvantaged groups may then influence the redistribution of transportation resources in an urban region. Equity planning, defined by Krumholz and Forrester (1990), is about promoting a wider variety of choices for people who have fewer ones. It is an important concept in transportation planning because decision-makers often make choices between maximizing transit user numbers or improving geographic coverage to less-populated areas (Walker, 2008). Yet, ridership numbers should not be the only basis for decision-making. Social outcomes are just as critical because socio-economic isolation intensifies when there are many transit-dependent residents without decent access to destinations (Garrett and Taylor, 1999).

The benefits of a transportation system can perhaps be best understood through the concepts of accessibility and mobility. Accessibility is defined as the amount of potential opportunities for interaction (Hansen, 1959) and focuses on the importance of reaching desired destinations, such as shopping, school, or work. Mobility, on the other hand, captures the ability of movement between different places (Morris et al., 1979). This paper posits that transportation benefits can be intuitively quantified as either a high number of destinations reachable within a certain threshold, or a short travel time to preferred destinations. In addition to accessibility, using travel time to real and observed employment locations has the benefit of moving beyond the abstract sense of regional accessibility. This measure is more valuable

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to an individual than a simple count of job opportunities—many of which may be undesirable or unattainable.

To assess equity, researchers in many fields use social indicators in order to identify socially disadvantaged populations. This study generates a social indicator to compare the level of accessibility to jobs and differences in transit travel times by social indicator levels in the region of Toronto, Canada. Using a rich dataset composed of all home-work location pairs (at the census tract level) for commuters in Toronto in 1996 and 2006, this research addresses the following questions:

- What are the relationships between socio-economic status and accessibility and transit travel time to jobs?
- How do these relationships change over time between 1996 and 2006?

This paper is organized into four sections. First, a literature review covers transportation studies on demography, equity, and social indicators. Second, a brief context outlines the background of Toronto, our study area. This is followed by a description of the methodology and data used in the paper. Then we present the results for changes in accessibility and travel time by social-indicator deciles between 1996 and 2006. Finally, the conclusion summarizes our findings and discusses ideas for future research.

2. Literature Review

The literature review is divided into three sections. The first discusses the relationship between transportation and population demographics, while the second examines the definitions of equity. The third section highlights some of the uses of social indicators in research.

2.1 Transportation and demography studies

Researchers have examined the link between transportation and population demographics for decades. Spatial mismatch theory posits that poor workers in American city centres live far from and have difficulty accessing job-rich suburbs (Kain, 1968). Most of this work in the U.S. context contends that areas with lower levels of accessibility relate to low income, black households near the city centre (Grengs, 2001). However, several studies find this definition too narrow for many circumstances. Many low-wage workers who live near city centres have high access to jobs in downtown and its vicinity due to employment density and better transit networks (Blumenberg and Hess, 2003; Hess, 2005). Glaeser et al. (2006) find that in older cities, such as New York and Chicago, low-income earners disproportionately live in central cities due to superior access to public transportation; nevertheless, the poor will relocate to the suburbs if jobs begin to decentralize. In Toronto's Census Metropolitan Area, senior and middle managers generally commute from the suburbs, while professionals, clerks, clerical workers, intermediate service and sales workers tend to commute from areas near the city centre (Moos and Skaburskis, 2009). Wachs and Kumagai (1973) find differences in accessibility by car to jobs by income levels; interestingly, middle-income workers have the lowest job accessibility in their study.

The concept of transportation mismatch may be a better explanation for why disadvantaged neighbourhoods or populations sometimes have difficulty accessing jobs other than the physical distance between home and work (Kawabata, 2003; Ong and Miller, 2005). The term modal mismatch has also recently entered the literature (Blumenberg and Manville, 2004; Grengs, 2010). These related concepts refer to the difficulty of reaching desired destinations without a car. While arguably already implicit in spatial mismatch theory, transportation and modal mismatch explicitly capture the fact that two areas in a city may not be separated by a great distance but may not be connected by reliable or viable public transit. Therefore, those reliant on public transit may not be able to access certain areas easily while car drivers can. This disparity can have a profound effect on life choices for those who do not own a car. In his interviews with the working poor, Boshmann (2011) finds that workers select home locations based on transportation, not job location, because travel dictates their ability to reach jobs. Interestingly, the interviewees want better transit, not assistance with car ownership. Better transit accessibility to jobs does in fact increase workers' chances of being employed and working close to full-time hours (Kawabata, 2003). Not only does better job accessibility by transit for lower-wage workers address equity concerns, but it aids a regional economy and labour market by allowing for better worker-job matches across an urban region. Thus, the studies discussed above show the important role that a public transit system can play in generating job accessibility for socially disadvantaged workers.

Beginning with Alonso (1964), much work has examined the factors that underlie the spatial distribution of various socio-economic population groups in a region. Glaeser et al (2006) examine the role that transport plays in residential sorting of rich and poor residents of large cities, finding that better public transportation in central cities explains much of this pattern. However, this study was limited to the US context; cities in Canada and elsewhere may show different patterns. The predominant pattern in many US cities has wealthier residents living in the suburbs, while lower-income (and often minority) residents live in central cities. However, in other countries this pattern can vary greatly—or even be reversed—with higher income residents concentrated downtown (Bruekner et al., 1999). These patterns are subjected to change over time due to changes in transportation systems or changes in land-use policies in a region. Furthermore, few studies have examined changes in transportation networks and residential patterns simultaneously.

2.2 Definitions of equity

With the importance of transit systems connecting homes to jobs established, planners must then choose how to define equity. Determining equity is difficult because there is no standard definition of distributional equity for transportation benefits (Martens et al., 2012). Transportation benefits include high accessibility to opportunities, short travel time, long service hours, short wait and transfer times, and routes that reach desired opportunities. Although it is common to mention equity in transportation planning documents, very few explain how it is measured or include performance measurements to follow up on this goal (Manaugh and El-Geneidy, 2011). Even the equity goal itself is often vague (Martens et al., 2012). This is likely due to debates over the definition of equity and the difficulty associated with implementing it in practice (Preston, 2009). Nevertheless, there are several ways to approach equity. Horizontal equity distributes benefits evenly to all groups. Some studies use this concept to define equity as equality in terms of uniform spatial distribution in a geographical region or the same distance from each resident to public facilities (Chang and Liao, 2011; Tsou et al., 2005). Yet measuring uniform distribution or distance ignores varying population densities in regions and fails to assess whether all residents require the same level of access to benefits. Therefore, these approaches offer very limited insight into equity considerations. Trying to achieve complete equal distribution of location-based benefits in space is nearly impossible. As cities naturally develop centres and peripheries, it is unavoidable that residents will have unequal access to opportunities (Martens, 2012).

To account for regional variation, it is more realistic to employ a range of acceptable distribution. Martens, et al (2012) suggest measuring transportation equity with two principals, based on Rawls' *Theory of Justice* (1971). First, maximize the average access to transportation while maintaining a certain minimum for all; second, maximize the average access while constraining the range. These principles address the difficulty of defining equity as equality for spatial benefits because it does not require a uniform amount of benefits for each person or group (Martens et al., 2012). At the same time, aiming for a narrow range could diminish transportation benefits for some in order to increase the benefits for others. To remedy this, in light of equity planning, Murray and Davis (2001) emphasize that transit access should be available for populations with the greatest potential need for subsidized transport. This is commonly called vertical equity: benefits are intentionally provided for one group, often low income, who cannot reasonably afford the price of transportation. Thus, we understand that an equitable distribution of transportation benefits, particularly public transit, first maintains a decent level of benefits for socially disadvantaged groups, then maximizes the average for all and narrows the range.

A number of studies evaluate transportation systems to determine gaps or find optimal improvements with particular attention to equity principles or disadvantaged groups (Manaugh and El-Geneidy, 2012). Evaluation methods include defining the levels of transit service to evaluate disadvantaged populations' access to public transit projects (Murray and Davis, 2001). Another method determines changes in public transport access levels with hypothetical network changes (Wu and Hine, 2003). A final method amends multi-criteria analysis to include quantified equity impacts of potential projects (Thomopoulos et al., 2009). While useful, most of these studies do not use actual home and work location data. To determine if a transit system is equitable and serves socially disadvantaged populations, it is critical to understand where people travel to and from in a region in addition to their level of access to public transport. Due to data availability, actual commuting patterns are less commonly examined, and few studies look at how regions change over time.

2.3 Social indicators in research

Since socially disadvantaged groups should receive some special attention in transportation planning, defining these groups is a very important step. A common way to define these groups is by using a social indicator. Social indicators identify underprivileged groups lacking access to goods and resources compared to the rest of the society at large (Townsend et al., 1988). The use of social indicators gained prominence in the health field in the 1980s (Bauman et al., 2006; Jarman, 1983; Townsend et al., 1988). Social indicators have been widely used to measure a variety of equity issues, including community deprivation (Sànchez-Cantalejo et al., 2008; Social Disadvantage Research Centre, 2003). Research that uses social indicators uses several different methods. The cumulative method is common, due to its ease in interpretation and simplicity in calculations. Some social indicators are derived from sums of variables (Bauman et al., 2006), while others weight variables equally (Townsend et al., 1988). Meanwhile some studies use the total of standardized values (Manaugh and El-Geneidy, 2012). More complicated methods assign various weighting to each variable (Social Disadvantage Research Centre, 2003). There are different methods used in the literature for the weighting of variables. One weights the variables by number of survey responses (Jarman, 1983), while another uses factorial analysis to determine weights (Sànchez-Cantalejo et al., 2008). Choosing variables to be included in the indicator is perhaps the most important aspect of generating a social indicator. Common variables include unemployment, household income, elderly, children, and minorities (Church et al., 2000; Dodson et al., 2006; Jarman, 1983; Manaugh and El-Geneidy, 2012; Stanley, 2012). Some variables are debated in the literature. For example, car ownership , although quite common, is considered a poor proxy for household deprivation (Townsend et al., 1988) since owning a car may be necessary for disadvantaged households if they have poor access to public transit, although owning a car can be a significant financial burden on some families (Johnson et al., 2010). Moreover, car ownership may reflect population density more than ability to own a car (Christie and Fone, 2003). Thus, variables in a social indicator must be selected to reflect the characteristics the research is trying to reveal.

3. Methodology & Data

To assess the level of transit service being offered by the existing system to both socially disadvantaged and non-socially disadvantaged groups, this study uses both mobility (travel time) and accessibility (gravity-based) measures. A combination of both measures is useful since both temporal and spatial distribution of opportunities is considered by commuters when deciding mode choice, home location, and employment location (Morris et al., 1979). In this study, differences between socially disadvantaged groups and the rest of the population, as well as differences between 1996 and 2006, are measured through a series of paired and unpaired *t*-tests conducted with statistical analysis software. Scatterplots and other graphs present, visualize, and analyze the data. The following sections describe the data sources and methods used to complete the analysis.

3.1 Social indicator

In order to generate the social indicator, it is first necessary to choose and locate the most relevant variables. Using census-tract level data, it is important to note that not everyone in a socially disadvantaged area is deprived, and likewise everyone who is deprived does not necessarily live in a socially disadvantaged area (Townsend et al., 1988). The selection of variables should be appropriate for the country (Sànchez-Cantalejo et al., 2008) in order to compare differences in a country's population. For example, in Ireland Wu and Hine (2003) compare Protestants' and Catholics' access to buses because these groups are spatially separated, while Sanchez-Cantalejo et al. (2008) uses illiteracy in Spain to identify social disadvantage. For this study, we use variables that are appropriate for a Canadian context. As this research has a focus on employment accessibility, variables used in literature that are not directly related to commuters are excluded from this study. These include seniors, youth, family type, disabled persons, and health. We use four variables to measure social disadvantage in terms of commuting to work including the two most common variables from the literature and two country-appropriate variables (Statistics Canada, 1996a, 2006a):

- median household income,
- percentage of labour force that is unemployed,
- percentage of population that has immigrated within the last five years, and
- percentage of households that spend more than 30 percent of income on housing rent.

Percentages are used in order to compare census tracts with different numbers of residents (Ong and Miller, 2005). In Canada, recent immigrants represent a significant group in major urban centres. Almost three quarters of new immigrants settle in Toronto, Montreal, and Vancouver (Heisz and Schellenberg, 2004). Partly as a result of the rules and regulations of Canada's immigration system, immigrants have, on average, higher levels of education compared to Canadian-born residents (Statistics Canada, 2004). Nevertheless, recent immigrants are more likely to work for lower wages, be employed in lower-skilled jobs, and have higher rates of unemployment compared to Canadian-born residents (Statistics Canada, 2004). In addition, immigrants also have a greater propensity to commute to work by public transit. In

Toronto, 36% of immigrants who arrived within 10 years commute by transit compared to 21% of Canadian-born commuters (Heisz and Schellenberg, 2004). Consequently, recent immigration status is a relevant variable to include in a Canadian social indicator compared to education level that is widely used in other countries.

The second country-appropriate variable is households spending more than 30 percent of income on rent. The national housing agency, Canada Mortgage and Housing Corporation (2011), defines housing affordability as spending no more than 30 percent of income on shelter costs. Furthermore, renter households spend noticeably less on basic necessities, such as food, shelter, and clothing, on average compared to owners (Luffman, 2006). Thus, the variable of renter households that pay more than 30 percent of income on rent shows the burden of housing costs relative to other expenses. It provides a more nuanced description of a household's economic situation than median income alone.

A correlation matrix is used to verify that the selected variables relate to each other and describe similar groups. All four variables have a statistically significant Pearson correlation (above 0.5) for 1996. For 2006, the four variables were significantly correlated as well, or highly correlated (above 0.46). Each of the variables is standardized for comparison purposes, weighted equally, and summed to create the indicator value. Some census tracts are excluded from the analysis due to the fact that there is no residential land use, or the data are not reported in the census. The indicator is grouped by deciles. Each decile contains 10% of the census tracts included in the data. Grouping the social indicator scores by deciles shows if there are trends in accessibility and transit travel time by social groups, with particular attention to the most socially disadvantaged populations (decile 1).

3.2 Measuring job accessibility

Accessibility may be measured in many ways (see Geurs and van Wee (2004) for a thorough review of accessibility measures). The gravity-based measure of accessibility attempts to model travellers' perceptions that closer opportunities are more desirable than farther ones. Gravity-based accessibility is often used in studies to measure accessibility to jobs (El-Geneidy and Levinson, 2007; Hess, 2005; Manaugh and El-Geneidy, 2012). A negative exponential decay curve is derived from Toronto area origin-destination survey data. The same travel decay functions for 1996 and 2006 are used since separate 1996 data are unavailable. Employment numbers were provided by Statistics Canada (Statistics Canada, 1996b, 2006b). The transit travel time matrix was obtained from the University of Toronto at the Traffic Analysis Zones (TAZs) level of analysis. Using a Geographic Information System (GIS), TAZ centroids are matched to the closest census tract. For census tracts with multiple TAZs, an average of the TAZs' transit travel time is used. Analyzing census data from two separate years requires consistent geographical boundaries. In 1996, there were 679 census tracts in the study area, and 821 in 2006. Census tracts are divided over time to maintain a given population in each. Using GIS, we pair the 1996 and 2006 census tracts to compare each year.

Accessibility can be calculated for different categories of opportunities. In addition to measuring accessibility to all jobs, this study analyzes accessibility to two job categories: low skill jobs and all other jobs. This was accomplished using the ten job categories defined in the National Occupational Classification matrix 2006 (Human Resources and Skills Development Canada, 2009). Low-skill jobs are the four job categories that usually do not require university education and include skills with on-the-job training (these are sales and service; trades, transport, and equipment operators; primary industry; processing, manufacturing, and utilities). All other jobs include the remaining five job categories that usually require university education and do not require skills learned on the job (these are business, finance and administration; natural and applied sciences; health; social science, education, government service, and religion; arts, culture, and recreation).

3.3 Measuring transit travel time

In addition to the broad measure of regional accessibility, this study also captures estimated transit travel time to actual work locations for all workers in the region. A dataset provided by Statistics Canada (1996b, 2006b) contains the home and work locations for all workers in the Toronto region at the census tract level. Commuters are allocated to one of the Statistics Canada job categories and rounded to the nearest five (for confidentiality purposes). The modeled commute times are very detailed. They include walking to and from transit locations, wait time, time in vehicle, and transfer time. For this study, these times are summed together for a total door-to-door commute time (see Day et al. (2010) for modeling transit times). Transit travel times were modeled slightly differently in 1996 and 2006, with one preferring the closest stop, and the other allowing for longer walking times. Thus, we use standardized values in this study in order to be able to compare the relative standing of different groups. Commuters sharing the same origin-destination pairs are given the same commute time, while actual commute times vary in reality. Intra-census tract commuting is not included in the modeled commute times as it represents a small portion of total commuters. Other aspects of travel, including trip-chaining, other required stops, or route diversions, are not accounted for in the modeled journey-to-work commute times by transit.

For some origin-destination pairs, the model calculated transit as an unfeasible mode. This includes instances in which a trip would be “unnecessary” (that is, people are unlikely to take a bus for 30 seconds and are more likely to walk instead) and a trip where access time would be too long, making the trip unfeasible. To include these census tracts in the analysis for year-to-year comparisons, we added walking time to the closest centroid with feasible transit time in addition to the estimated travel time of this closest centroid. This was calculated using a street network in GIS and using 5.47 km/hour walking speed (Krizek et al., 2012). It is important to note that the transit travel time is the time it would take *if* a commuter took transit: this does not imply that all commuters actually took transit. In this way we measure the potential transit benefit that the current system offers to residents based on the locations of their home and work, regardless of their actual selected mode. In this way we measure the potential benefit that the current system offers to residents based on the locations of their home and work.

4. Context

The greater Toronto region is the most populated area in Canada. Total jobs increased from 2,236,381 in 1996 to 2,638,537 in 2006, while the total employed workforce increased from 2,161,339 in 1996 to 2,521,545 in 2006 (Statistics Canada, 1996b, 2006b). With a growing workforce, accessibility to jobs for workers is increasingly important. Both population and employment concentration show a suburbanization trend. This shift may be influenced by construction of the tolled Highway 407 north of the city centre, as the highway offers faster connections to residents in these areas and greater access to labour for businesses. The region, particularly the City of Toronto, is well-served by bus, subway, and commuter rail transit. During the study's time period, there were two significant infrastructure additions to public transit (Figure 1). The first is the 5.5 km Sheppard subway line with five new stations. The second is seven new GO Train stations along the existing commuter train network. The bus network experienced several changes as well, including express bus expansions. In the Toronto region, fewer residents take transit as they live farther from the city centre. Around 53% of commuters who live within 5 km of the city centre take transit; this drops to 10% when commuters are located 15 to 20 km away from the city centre (Statistics Canada, 2005).

For our research, we selected the City of Toronto and the adjacent municipalities that have significant public transit connections to the City of Toronto (Figure 1). The maps make use of data and shapefiles from DMTI Spatial Inc. (2007) and ‘‘The Big Move: Transforming Transportation in the Greater Toronto and Hamilton Area’’ (Metrolinx, 2008). While data were available for the whole region, this area has the bulk of public transit routes, services, and connections in the region. It also has the highest variation of income levels. Thus, this study focuses on the most populous area with high levels of transit accessibility, including large areas with limited transit accessibility could potentially skew the findings.

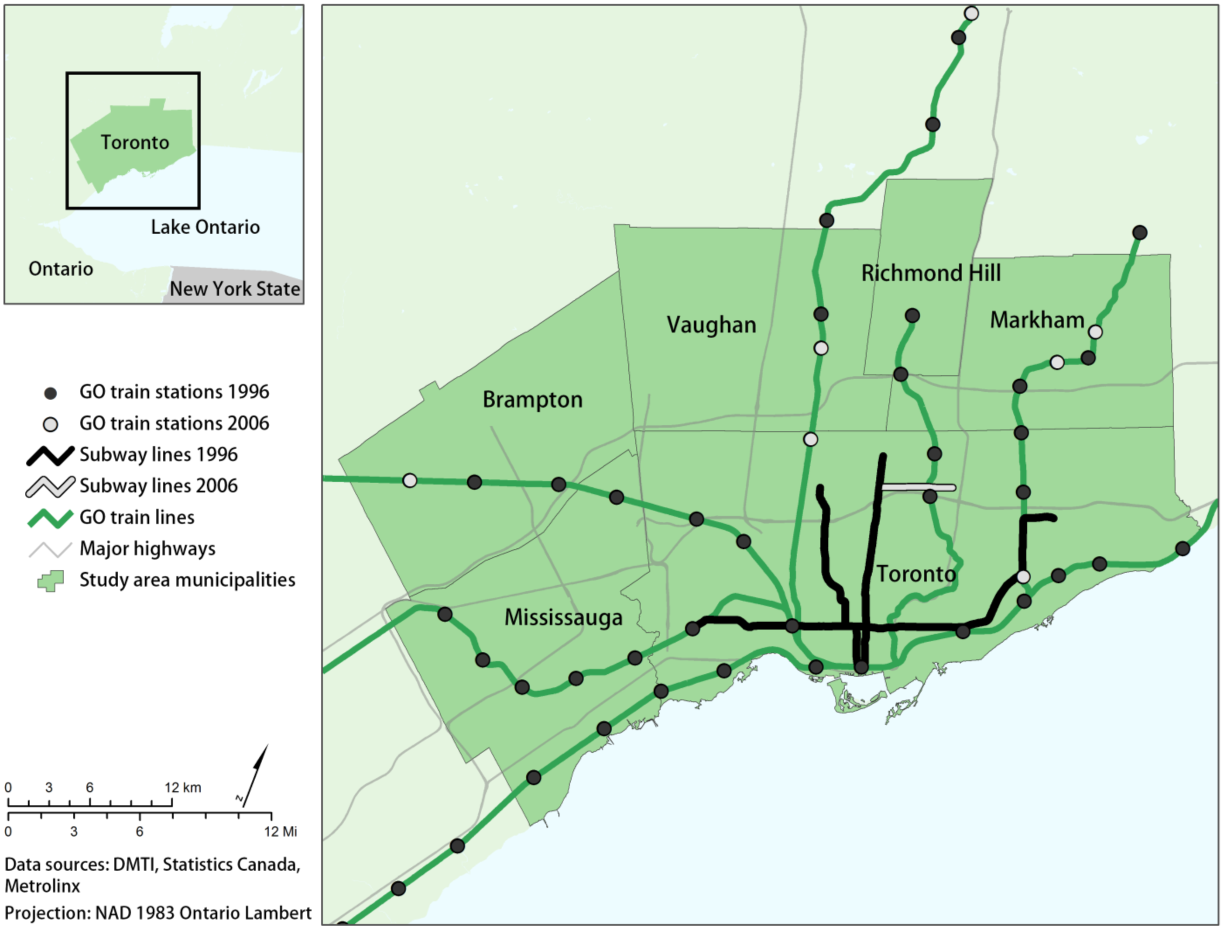

Figure 1: Context map

5. Findings

5.1 Regional trends

Figure 2 shows the spatial distribution of the social indicator deciles in both years. The lowest social indicator decile, outlined in black, represents the most socially disadvantaged census tracts. Some census tracts are excluded from the analysis and appear blank because land use is not residential, or the data are not reported in the census. There is a clear suburbanization trend for the most socially disadvantaged areas (Figure 2). From 1996 to 2006, the lowest decile increased an average of 1.3 km in Euclidian distance from downtown. An increase of 0.61 in standard deviation indicates that the lowest deciles are occupying more geographically diverse areas in 2006 when compared to 1996. Around 36% of the lowest decile census tracts in 1996 are no longer among the lowest decile of socially disadvantaged population in 2006. This can be related to the suburbanization of the socially disadvantaged populations, which may be linked to a variety of reasons including but not limited to increases in housing prices near the regional centre, suburbanization of jobs, and improvements in the transit network. Thus, it is clear that the most socially disadvantaged census tracts are increasingly located in geographically diverse areas.

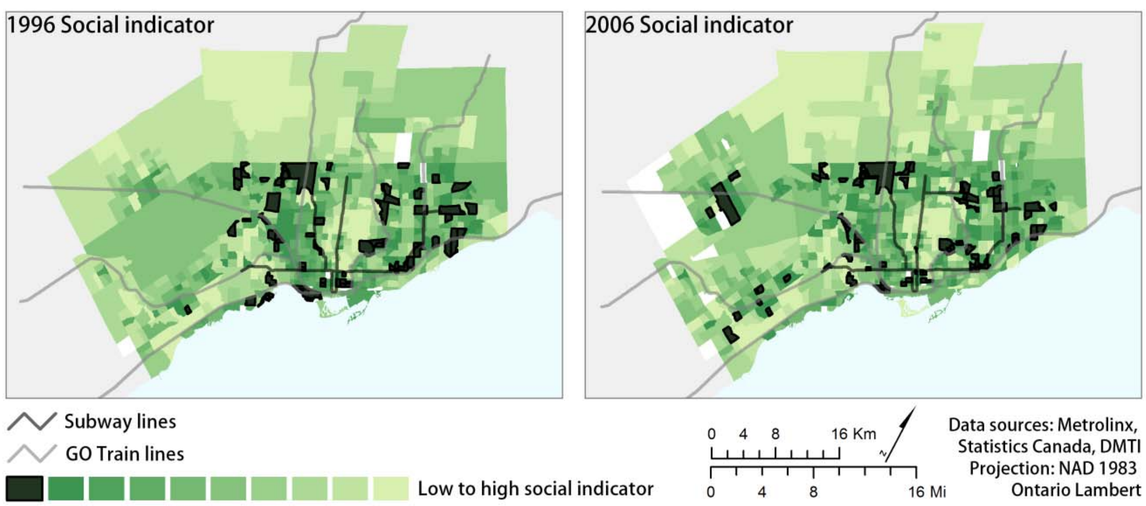

Figure 2: Social indicator deciles, 1996 & 2006

Figure 3 displays the spatial distribution of standardized accessibility to all jobs by census tract, and standardized transit travel time (not minutes) for both years. These standardized values compare each census tract's standing to the region in the same year. The accessibility maps show that higher levels of accessibility have spread outward in the region, with the core accessing the greatest number of jobs. For transit travel time, these maps show that some areas farther from the city centre have decreasing transit travel times relative to the rest of the region from 1996 to 2006. Over the ten-year time period, more census tracts have viable access to transit. In 1996, 4.4% of census tracts had over 85% of commuters with no viable transit options. This decreased to 1.3% of the studied census tracts in 2006.

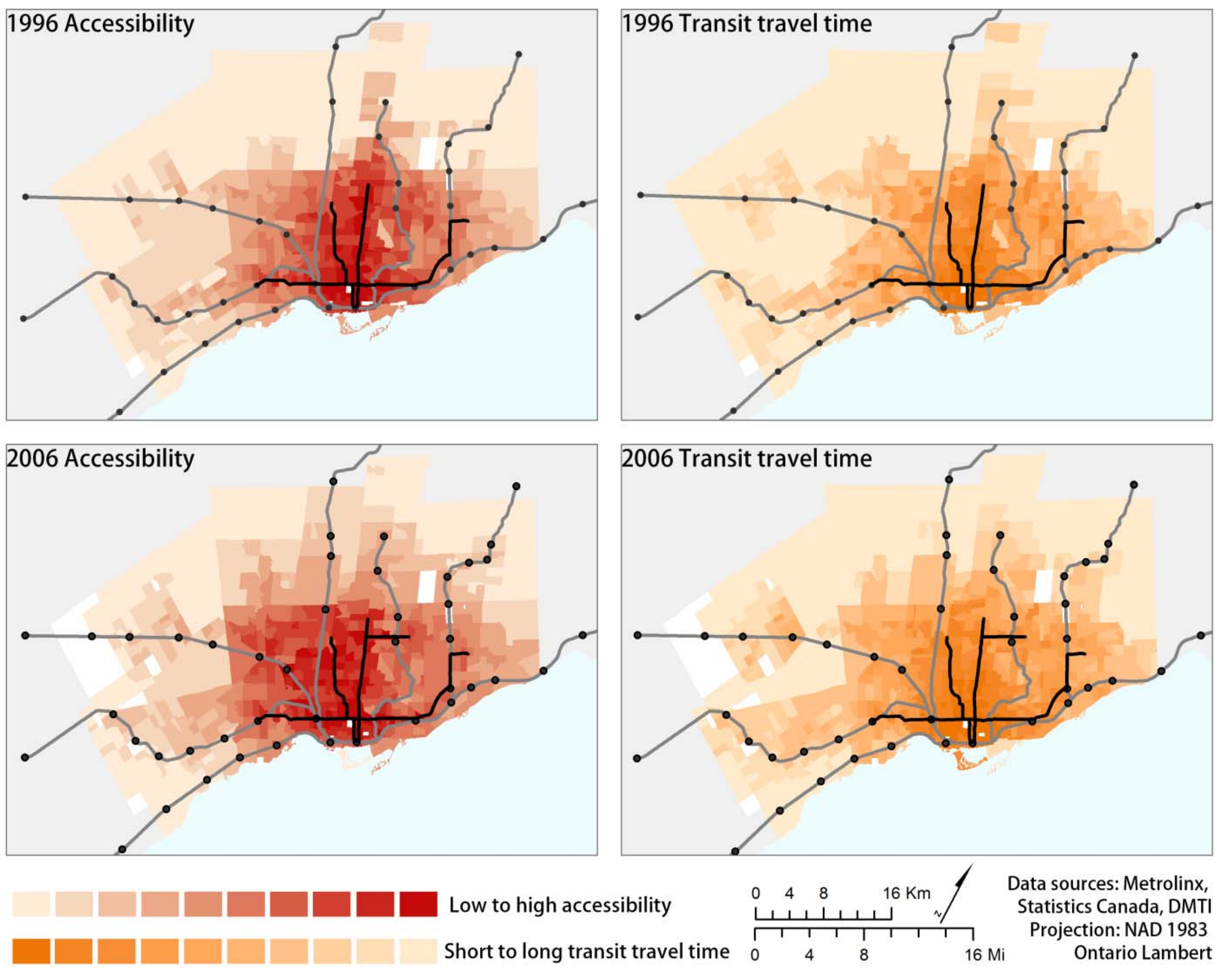

Figure 3: Relative accessibility & relative transit travel time to jobs by deciles, 1996 & 2006

In 1996, we find that the more socially disadvantaged populations have greater accessibility to jobs and shorter transit travel times compared to the rest of the region (Figure 4). Ten years later, the more socially disadvantaged populations continue to have higher levels of accessibility to jobs and shorter transit travel times compared to other census tracts in the study area (Figure 4). The main finding from the data displayed in the scatterplots is that the socially disadvantaged populations continue to have the most transit-related benefits in the region within the 10-year period. Interestingly, Table 1 shows that the range of the relative social indicator widens over the 10-year period. Some census tracts become much more socially disadvantaged than others. Comparing 1996 and 2006 in Table 1, the median level of the relative gravity-based accessibility to all jobs increases and the range narrows from 1996 to 2006.

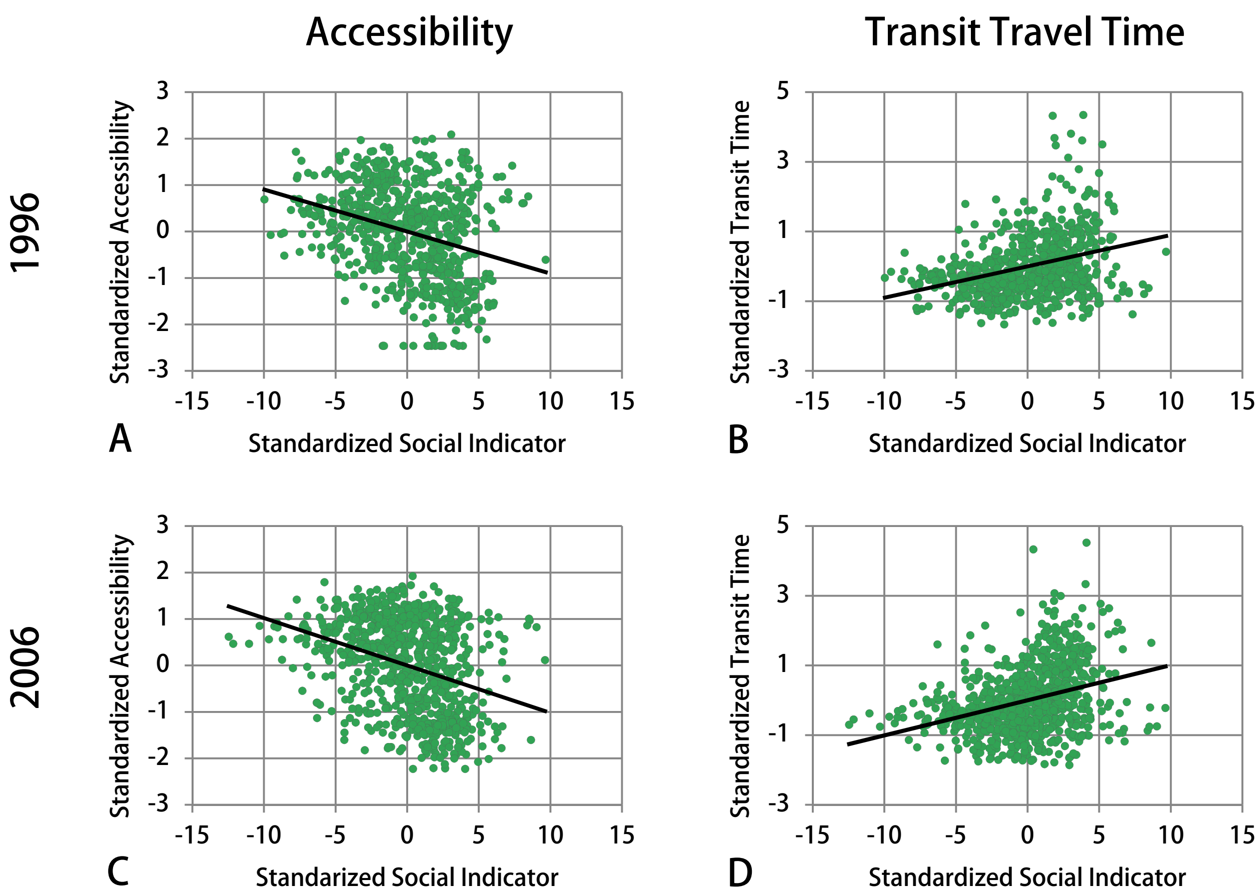

Figure 4: Comparing accessibility & transit travel time to the social indicator

Table 1: Standardized values of the dataset

	Year	Maximum	Minimum	Range	Median
Social indicator	1996	9.67	-9.96	19.63	0.27
	2006	9.63	-12.45	22.08	0.21
Accessibility	1996	2.09	-2.46	4.55	0.13
	2006	1.92	-2.23	4.15	0.18
Transit travel time*	1996	7.00	-1.67	8.67	-0.22
	2006	6.66	-1.86	8.52	-0.16

*note these are relative values, not units of time

In terms of accessibility, this finding is consistent with the equity principles of increasing benefit levels to all while narrowing the range. Thus, Toronto's transit system is becoming more equitable in terms of accessibility to jobs. When we analyze transit travel time, the range in times narrows slightly (Table 1). Note that these values are relative scores, and do not represent units of time such as minutes. However, in relative terms, commuters in 2006 have a slightly longer median transit travel time compared to 1996 (Table 1). Therefore, while accessibility to jobs is improving, transit travel time for actual home to work commutes is longer relative to the region in 2006 compared to 1996. Longer commute times are a reflection of the transit system, as well as changes in home and work locations, land use patterns, and commuters' willingness to travel. For instance, commuters may be more willing to commute to farther work locations with improvements in transit system infrastructure and service. Overall, the range for both transit travel time and accessibility narrows from 1996 to 2006. As well, the relative median level of accessibility increased over time, while the relative median level of transit travel time increased (longer travel times).

5.2 Trends by social decile

Figure 5 shows relative year-to-year accessibility and travel time values for each social indicator decile. Remember that decile 1 represents the most socially disadvantaged group. Grouping by deciles does not reflect the same distribution and range as the scatterplots; the purpose of the deciles is to compare the transit benefits for one decile to the rest in terms of range. As standardized values are used, a gain in one decile does not correspond to a direct loss or gain of benefits in another. Comparing the deciles in Figure 5, there is a clear divide in both accessibility and transit travel time for more socially disadvantaged deciles in contrast with less socially disadvantaged deciles. The general trend in both years shows that the socially disadvantaged deciles have relatively high accessibility to jobs; conversely, the least socially disadvantaged deciles have relatively low accessibility to jobs. In 2006, the most socially disadvantage group (decile 1) has the highest job accessibility relative to the rest of the region. For transit travel time, the most socially disadvantaged decile has one of the shorter transit travel time commutes relative to the other regional deciles in 2006. In terms of providing for groups that have the greatest potential to benefit

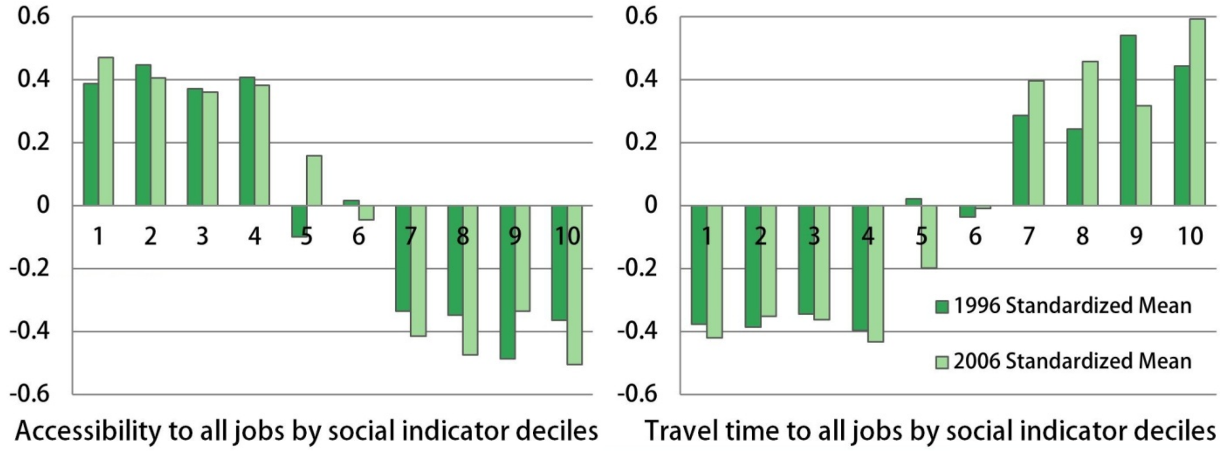

Figure 5: Accessibility and transit travel time by social indicator deciles

from public transit, Toronto's transit system provides the most socially disadvantaged groups with higher levels of accessibility and shorter transit travel times, in each year, relative to other social deciles in the region.

We also group the data by three job categories: all jobs, low skill jobs, and all other jobs. In all circumstances except one we did not observe that job categories had different results than all jobs; therefore, we report the findings for all jobs. Using two sample t-tests, we compare social indicator deciles in the same year. The t-tests demonstrate statistical significance of many findings displayed in the scatterplots and bar graphs. In 1996, the lowest decile has better accessibility, $t(677) = 3.39$, $p = .001$, and shorter transit travel times, $t(166) = -6.14$, $p < .001$, compared to all other deciles in the same year, as well as compared to the highest decile for all jobs (accessibility: $t(134) = 4.71$, $p < .001$, transit travel time: $t(81) = -4.71$, $p < .001$). As an equitable transit system should first maintain a decent level of benefits for socially disadvantaged groups, we find that in 1996 the Toronto transit system benefits the most socially disadvantaged census tracts for their commutes to real job locations. A decade later, these findings are consistent: the lowest decile has better relative accessibility, $t(819) = 4.55$, $p < 0.001$, and shorter transit travel times, $t(148) = -6.37$, $p < .001$, compared to all other deciles in the same year, as well as compared to the highest decile in 2006 for all jobs (accessibility: $t(163) = 7.15$, $p < .001$, transit travel time: $t(110) = -6.25$, $p < .001$). Thus, relative to all other census tracts in the same year, Toronto's transit system provides the best accessibility to jobs and shortest transit travel times for the most socially disadvantaged groups.

Regarding the changes over time, we compare the most socially disadvantaged decile in each year to determine relative differences. The lowest social indicator decile in 1996 improves in their level of accessibility to all jobs in 2006, compared to the other deciles, $t(81) = -6.14$, $p < .001$. Likewise, the census tracts that became part of the lowest decile in 2006 improves their accessibility to all jobs from their level in 1996, relative to the other deciles, $t(81) = -4.64$, $p < .001$. This demonstrates that both the

1996 and 2006 most socially disadvantaged decile improves their levels of accessibility to all jobs compared to the rest of the deciles.

In terms of commute time to all jobs, transit travel time significantly decreases over time for the lowest 1996 decile, $t(81) = 5.93$, $p < .001$, and the lowest 2006 decile, $t(81) = 4.12$, $p < .001$, compared to relative change in transit time for other deciles. Interestingly, the most socially disadvantaged decile in 1996 did *not* experience a statistically significant decrease in transit travel time to low skill jobs, $t(80) = 1.86$, $p = .066$. This finding is remarkable because low skill jobs represent the type of jobs that this group would most likely need to reach. In addition, comparing the lowest deciles in each year, accessibility to jobs and transit travel time did not change significantly, $t(148) = -0.77$, $p = 0.443$, and $t(148) = 0.51$, $p = 0.61$, respectively.

This means that regardless of the location of the lowest decile in each year, these census tracts did not experience a significant change in accessibility to all jobs, low skill jobs, or all other jobs, nor in transit travel time. From the results in the scatterplots, we know that the lowest social indicator decile has higher accessibility to jobs and lower transit travel time compared to all others. Not finding statistical significance simply confirms that the lowest decile in each year continues to have relatively high accessibility and low transit travel time. Lastly, we test if accessibility and transit travel time to different job categories changes at different rates over time. We find that low skill jobs and all other jobs changes at the same rate (since it is not significant) from 1996 to 2006 for both accessibility, $t(818) = 1.38$, $p = 0.168$, and transit travel time, $t(818) = 0.14$, $p = 0.892$. Thus, one job category is not gaining transit benefits over another during the ten-year period.

6. Discussion

Past work has examined accessibility over time (El-Geneidy and Levinson, 2007) or accessibility throughout the socio-economic spectrum (Fan et al., 2012). However, the authors are not aware of previous work that has looked at both simultaneously. Furthermore, while much work has examined accessibility and the location of socially-deprived neighbourhoods, this is the first time to examine these relationships in the Canadian context. Baum-Snow & Kahn (2005) do examine related issues but focus predominantly on transit ridership as opposed to how transport system benefits are distributed throughout society.

Our findings for transit travel time and accessibility to jobs do not support that the spatial mismatch hypothesis is present in Toronto from 1996 to 2006. While the more socially disadvantaged census tracts are located nearer to the city centre in 1996, some move outward in the region by 2006. Even with the changing dynamics of where socially disadvantaged areas locate in the Toronto area, the most socially disadvantaged census tracts have better accessibility to jobs and shorter transit travel times from home to work in 1996 and 2006 compared to all other groups. This is similar to Hess' (2005) finding that low-wage workers have the best accessibility to jobs, while workers not in poverty have the lowest employment accessibility. In terms of serving socially disadvantaged populations that stand to gain the most from public transit, Toronto's transit system and distribution of job locations serve these groups well. This shows that vertical equity continues to be present. Interestingly, these findings are in contrast with the conclusion of other research on Toronto (Hulchanski, 2007), which claims that low income populations have lower job accessibility and longer access time to jobs compared to the rest of the region. However, it should be noted that both the report's study area and methodology used to determine accessibility vary from our research. For example, the current research uses a robust transit travel time model and actual home and work locations. Hulchanski (2007) uses two simplified indicators: the number of subway stops in the area, and the number of jobs per 100 "working age population", which only approximate job accessibility or travel time to work. Thus, actual home-work location data provide a more accurate view of commuting patterns by transit in the region.

In this research we have shown that the residential location of socially disadvantaged commuters has been suburbanizing over the ten-year period. However, even with the trend of suburbanization, the most socially disadvantaged deciles have relatively high accessibility to all jobs and relatively low transit times compared the rest of the region in both 1996 and 2006. Over time, the most socially disadvantaged decile shows a statistically significant increase in accessibility and decrease in transit travel time. Current land use policies adopted by different cities that encourage building high-end residential properties in downtown and its vicinity are expected to have a similar effect on the suburbanization of the socially disadvantaged population. Yet the network structure and its changes in these cities are what will determine if similar changes in accessibility will be present or not. Overall, we find that Toronto's transit system moves towards a more equitable distribution of transit-related benefits from 1996 to 2006, while maintaining a high level of these benefits for the most socially disadvantaged groups. In other words, socially disadvantaged commuters continue to have a greater share of benefits, higher job accessibility, and lower relative transit travel time compared to the rest of the region in both years.

The results of this Canadian study differ from U.S. research on spatial mismatch hypothesis and transportation or modal mismatch. Literature from American studies tends to find that lower income groups have a more difficult time accessing jobs due to distance or transportation and modal mismatch (Grengs, 2001; Kain, 1968; Kawabata, 2003; Ong and Miller, 2005). Besides differences in commuting patterns from city to city, the results from this study emphasize that residential and work locations of the socially disadvantaged shift over time. As a result, transit providers need to be aware that transit systems must be flexible to adjust alongside changing commuting patterns.

7. Conclusion

By focusing on how the measurable benefits of a transport system changes over time, as well as who receives these benefits, this study offers an important analysis of how transport equity can be better measured and understood. While this study did not find patterns that would suggest a clear spatial or modal mismatch in Toronto, the authors certainly recognize that these patterns of injustice do exist elsewhere. This paper's primary contribution may be the generation of a new social indicator tailored to transportation studies. The methodology simultaneously accounts for differences in social need of the population, land use, and employment. The social indicator shows groups by social disadvantage deciles and measures their accessibility to jobs and relative transit travel time. It is a helpful tool for transportation planners when evaluating networks because it identifies who benefits from a transit network. This methodology could be applied to allow practitioners and researchers to locate where transit service levels should be maintained in case of funding cutbacks. Consequently, when transit agencies face funding shortfalls, service changes should be careful not to harm socially disadvantaged populations.

Every data set, model, and study has limitations. In this study, two models were used to calculate transit travel time in each year that used different assumptions; thus we are limited to using standardized values in order to compare year to year. An assumption in this study is that shorter transit travel times are inherently better. This risks missing the importance of transfers, comfort, and preference for modes of transit travel.

Suggestions for further research on this topic include comparisons of the mean and range of accessibility and travel time for automobiles to transit. This would help quantify the performance of Toronto's transit system. Such an analysis would show whether one mode is receiving an increase in transportation benefits compared to the other over time. In addition, origin-destination survey data could be analyzed to gain a better understanding of whether changes in transit systems encourage farther commutes. Another topic to pursue is to compare changes in neighbourhood clusters and their relationship to transit using spatial auto-correlation in a GIS. Finally, there are remaining questions regarding the relationship between changes in accessibility and the process of neighbourhood change and gentrification over time in the region.

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PART 2

DOES YOUR JOB MATTER?

HOW A CHANGING TRANSPORT SYSTEM AFFECTS TRANSIT MODE SHARE AMONG DIFFERENT OCCUPATIONS IN TORONTO, CANADA

1. Introduction

Increasing transit ridership is a central goal in most recent regional transportation plans in Canada (City of Montreal, 2008; City of Vancouver, 2012; Metrolinx, 2008). This is in response to several pressing needs, including the desire to alleviate road congestion, respond to road capacity demands, decrease emissions and other environmental impacts, address social equity issues, and attend to mobility needs of an aging population. Moreover, regional and municipal governments are making substantial investments in new transit infrastructure to encourage car drivers to switch to public transit for daily commutes.

In order to understand how to increase public transit mode share in urban areas, it is imperative to first understand the determinants of transit use. The link between transit infrastructure and destinations is key for understanding transit use since travel is usually understood to be a derived demand. In other words, people travel most often for the primary purpose of reaching destinations, not to travel for its own sake. While new transit infrastructure would be expected to increase transit ridership, research in recent years has underscored the importance of a variety of factors that influence the decision to take transit. Studies that focus too heavily on proximity to stations when predicting future ridership (Lindsay, Schofer, Durango-Cohen, & Gray, 2010) might miss the fact that mode decisions are based on a variety of factors. Mode choice literature shows that there are a variety of influential factors such as urban form or infrastructure (Bento, Cropper, Mobarak, & Vinha, 2005), individuals' attitudes (Kitamura, Mokhtarian, & Laidet, 1997), and social demographics (Shen, 2000).

Socio-economic characteristics raise concerns about transit equity for socially disadvantaged populations. Some argue that particular attention should be given to these groups in transportation planning (Murray & Davis, 2001). In the Toronto region, previous work shows that the most socially disadvantaged areas have better accessibility to jobs by transit and lower transit travel times relative to the rest of the region (Foth, Manaugh, & El-Geneidy, 2013). Additionally, some of the most socially disadvantaged areas became more suburban between 1996 and 2006. The movement of socially disadvantaged groups away from the downtown's concentration of transit services is a concerning trend in terms of providing transit services to those who may benefit the most. In addition, car and transit infrastructure was built during this 10-year period. These changes in both socially disadvantaged residential locations and the introduction of new transport infrastructure in the Toronto region led us to question whether these significant changes influenced transit use over time. Using two years of data, before infrastructure investment and after, we explore how infrastructure and socio-economic factors affect changes in transit mode share over time.

The bulk of mode choice literature examines commuter trips; however, most studies do not distinguish between different types of work trips (Limtanakool, Dijst, & Schwanen, 2006; Wang, 2001). This research presents a novel way of disaggregating the journey to work by job categories to understand differences in transit use over time. Do retail sector commuters respond to a change in accessibility to jobs by transit more or less than trades sector employees? Does social disadvantage matter? These questions sit at the nexus of land use and transport planning as planners and engineers attempt to align transit supply and social equity outcomes with travel demand to desired destinations. Thus, this study uses statistical modeling techniques to explore whether the determinants of transit mode share for different job categories change over time in Toronto, Canada.

The article is structured into five sections. First, a literature review covers mode choice research and common variables used in these studies. Second, the context of the Toronto study area is presented. Third, the methodology section outlines the statistical modelling method, variables used and expected outcomes. The fourth section presents the data sources. The findings section explains trends in commuting and statistical model outcomes, then the discussion compares findings with previous research. Last, the conclusion summarizes the findings and implications of this research.

2. Literature Review

Mode choice has been a subject of study for decades, and most of the explanatory variables fall within two main groups: socio-economic factors and built environment characteristics (Ewing & Cervero, 2001). This literature review is divided into three sections. The first two parts discuss how travel behaviour is influenced by socio-economic factors and the built environment, respectively, while the third section addresses travel by occupation type.

2.1 Socio-economic variables & indicators

Mode selection partly depends on the personal characteristics of travellers. Income is the most prevalent of the socio-economic variables used in mode choice studies. It is used to simulate the ability to pay for travel, the mode choices available, and residential decisions in terms of housing cost and proximity to transport networks or employment opportunities. Researchers use income to describe social exclusion, transport disadvantage, and transport equity issues (Giuliano, 2005; Mercado, Páez, Farber, Roorda, & Morency, 2012; Roorda, Páez, Morency, Mercado, & Farber, 2010; Vasconcellos, 2005).

Lower income at the household or neighbourhood scale is associated with higher transit use (Bento et al., 2005; Giuliano, 2005; Hine, 2004; Moniruzzaman & Páez, 2012) and greater transit dependency, defined as no driver's license or access to a car (Polzin, Chu, & Rey, 2000). Consequently, when many transit-dependent residents do not have adequate access to destinations, social isolation can intensify (Garrett & Taylor, 1999). Lower incomes also relate to other aspects of travel behaviour including shorter commute duration and distance (Giuliano, 2005; Shen, 2000), fewer generated trips (Roorda et al., 2010), and selecting residential locations close to better transit facilities, which often tend to be downtown (Blumenberg & Hess, 2003; Glaeser, Kahn, & Rappaport, 2006; Hess, 2005). Another commonly used explanatory variable is immigrant status: immigrants are found to patronize transit more (Liu & Painter, 2011; Mercado et al., 2012; Taylor, Miller, Iseki, & Fink, 2009). In terms of different transit types, higher education positively influences train patronage, although it is negatively related to bus use (Bento et al., 2005; Limtanakool et al., 2006). Other factors significantly correlated with greater transit use include younger age (Chen, Gong, & Paaswell, 2008; Mercado et al., 2012), and being female (Bento et al., 2005; Cervero & Kockelman, 1997; Limtanakool et al., 2006; Mercado et al., 2012).

Nevertheless, a combination of several socio-economic factors often plays a role in mode choice. To capture varying socio-economic characteristics, many studies employ a composite social disadvantage indicator (Bauman, Silver, & Stein, 2006; Currie, 2004; Foth et al., 2013; Jarman, 1983; Manaugh & El-Geneidy, 2012; Sànchez-Cantalejo, Ocana-Riola, & Fernàndez-Ajuria, 2008; Social Disadvantage Research Centre, 2003; Townsend, Phillimore, & Beattie, 1988); see Part 1 for a review of social disadvantage and social equity literature. This study seeks to further test the use of a social disadvantage indicator for transport studies by assessing commuting differences by job category.

2.2 Built environment variables & accessibility

In addition to socio-economic characteristics, mode choice is influenced by the environment in which travel occurs. In a review of the influence of the built environment on travel behaviour, Cao, Mokhtarian, & Handy (2009) confirm that built environment characteristics are indeed influential on travel behaviour, even when accounting for self-selection. Travel occurs within the built environment, which includes transportation infrastructure and networks. Residential proximity to bus stops is correlated with higher levels of transit ridership (Ewing & Cervero, 2010; Moniruzzaman & Páez, 2012), while others find that destination density is a more important factor to decrease commutes by car (Chen et al., 2008). However, not all transit modes are considered equal by users. Bento et al. (2005) concludes that a 10% increase in bus supply results in a 1.3% decrease in the probability of driving, while adding the same amount of rail supply is estimated to decrease driving by 4.2%.

A measure that accounts for both transport infrastructure networks and ease of reaching destinations is accessibility. Accessibility measures the number of potential opportunities for interaction (Hansen, 1959), such as jobs, schools, or workers. It also can be used to monitor changes in a region over time (El-Geneidy & Levinson, 2007). Accessibility measures are valuable because they uniquely combine the built environment, transit infrastructure, and the spatial distribution of destinations. Many commuting studies use accessibility to assess time and distance. Areas with high accessibility generally allow residents to spend less time travelling to reach more destinations compared to areas with low accessibility. Higher accessibility to jobs corresponds with shorter commutes (Levinson, 1998), and explains about half the variation in commute distance (Wang, 2000), or 10% variation in commute time when comparing regression models (Shen, 2000).

Accessibility affects mode share as well. Chen et al. (2008) find that high job accessibility by transit at work significantly predicts a decrease in car mode share. While accessibility is prevalent in transport literature, the measure of access to destinations by transit networks is only beginning to enter mode share studies (Moniruzzaman & Páez, 2012). By measuring the destinations that can be reached using a transit network, accessibility by transit has a distinct meaning from access to transit, which simply measures proximity to a transit stop. Accessibility by transit has a positive influence on transit use. Moniruzzaman & Páez (2012) find an increase of accessibility to 10,000 jobs relates to a 0.2 to 0.5% increase in transit mode share. There are several ways to calculate accessibility. For a complete review of accessibility measures, see Geurs & van Wee (2004). Accessibility can also assess longitudinal changes in a region. When new transport infrastructure is built, or land use changes occur, the accessibility to destinations also shifts accordingly. Thus, accessibility can be used to explore how mode shares respond to changes in transport systems and land use patterns.

2.3 Travel by job categories

Many of the aforementioned studies do not distinguish between occupational categories. Some studies assess mode share differences by household income categories (Fan, Guthrie, & Levinson, 2012; Mercado et al., 2012), and a few studies consider job type for certain travel characteristics. For example, professionals tend to have longer commute durations (Shen, 2000). In Toronto's Census Metropolitan Area, Moos & Skaburskis (2009) find that managers commute from the suburbs, and professionals, service and general office workers commute from the central city. Lin & Long (2008) use job categories to define neighbourhood type in their travel behaviour study, but do not isolate job category from other variables to determine travel patterns. Assessing determinants of mode share by job category has the potential to contribute more variegated findings to mode share and commuting research than an aggregated work category. Therefore, this research investigates whether determinants of transit use vary between workers in different job categories.

3. Context

The Greater Toronto and Hamilton Area is Canada's most populous region. For this study, the City of Toronto and its surrounding municipalities of Mississauga, Brampton, Vaughan, Richmond Hill and Markham are selected because these suburban municipalities have significant public transit connections with Toronto (Figure 6). The Toronto region serves as a good case study as there were several changes to the region's transport infrastructure from 1996 to 2006. Highway 407, a tolled expressway opened in 1997, augments accessibility to destinations for suburban municipalities surrounding the City of Toronto. In addition, the transit system had capital improvements as well. In 2004, the Sheppard subway extension began operation with four new stations. Moreover, seven new GO Train (heavy rail) stations were added to the commuter rail network, bringing the total to 56 within the study area.

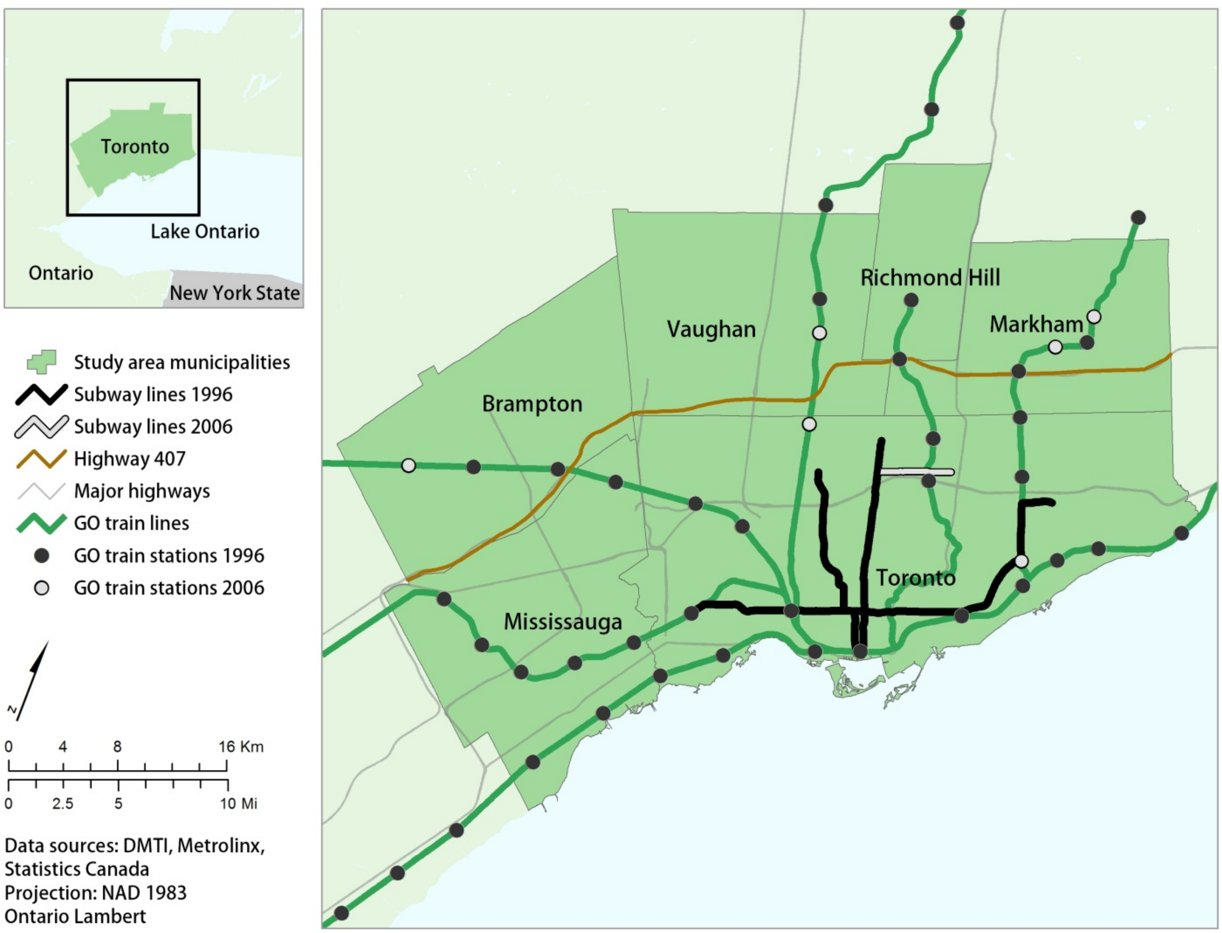

Figure 6: Context map of study area

The Toronto region also experienced demographic changes. The region grew in both population and jobs between 1996 to 2006 with a general trend of suburbanization for both (Manaugh, Foth, Willis, & El-Geneidy, 2012). Notably, the 10% most socially disadvantaged areas show a suburbanizing trend from 1996 to 2006 (Foth et al., 2013). The York region (which includes Vaughan, Richmond Hill, and Markham) had the largest increase in both population and jobs. Both the York region and Peel region (which includes Mississauga and Brampton) experienced a 32% and 14% increase in the manufacturing sector respectively. Moreover, these two regions also had over 15% of growth in the trade industry. Conversely, Toronto had a significant decrease in manufacturing and trade jobs, roughly 14%, and well as the slowest growth overall. The shifting concentrations of population and employment change the spatial relationship between home and work, with some job types experiencing more change than others. In turn, these changes in the urban region influence the transport modes selected for home-to-work commutes.

4. Methodology

To determine which explanatory variables influence commuters' selection of transit, and to understand if these determinants vary by job category, we use multiple linear regression analysis. Before selecting the variables, it is important to specify the unit of analysis. Many commuting studies use the individual or household unit (Bento et al., 2005; Levinson, 1998; Mercado et al., 2012; Vega & Reynolds-Feighan, 2008), while others use aggregate data such as block (Shen, 2000), dissemination area (Moniruzzaman & Páez, 2012), Traffic Analysis Zone (TAZ) (Wang, 2000), and census tract (Chen et al., 2008). In order to test how accessibility relates to transit mode share, the TAZ spatial unit will be used. Hence, the other variables must match this level of analysis. At the TAZ aggregate level, findings will demonstrate regional trends.

We use four regression models to show the differences between job categories. The first model tests the independent variables for all jobs types. The other three models analyze the same variables by job category: office/professional (office), retail/sales/service (retail), and manufacturing/construction/transport (trades). The dependent variable in the respective models is the percentage of transit share by TAZ for each job category. The selected explanatory variables fall in three categories: accessibility, social disadvantage, and transport networks, plus a year dummy to capture the general changes in transit mode share between 1996 and 2006.

First, accessibility to jobs (by category) by transit measures the potential benefits that the transit system provides TAZ residents. Accessibility to jobs by transit captures the influence of land use and transport together. Studies often use the gravity-based measure to calculate accessibility to jobs (Cervero & Kockelman, 1997; Chen et al., 2008; El-Geneidy & Levinson, 2007; Foth et al., 2013; Hess, 2005; Manaugh & El-Geneidy, 2012). We hypothesize an increase of accessibility by transit to jobs, both in general and skills-matched, corresponds with a higher likelihood of riding transit to work in both years. These findings will be of particular interest since transit accessibility has not been widely used in mode share studies. In terms of job categories, we estimate that office jobs would respond the most to an increase in accessibility since these jobs tend to follow regular business hours, when transit services are most available. Further, an interaction variable of accessibility and social disadvantage indicator tests whether the decile (10% of TAZs) of most socially disadvantaged commuters will take transit more if there is higher accessibility to jobs by transit available compared to less socially disadvantaged groups. We expect that the most socially disadvantaged TAZs are likely to take transit more compared to other groups. To assess change over time, we test whether accessibility to jobs becomes more important for predicting transit share in 2006 than in 1996 using a year interaction variable. Finally, we include accessibility to respective job categories by car, as well. This variable is expected to show a negative correlation with transit share.

The next group of variables accounts for socio-economic characteristics, specifically social disadvantage. We use a composite social disadvantage indicator developed in Part 1 for travel behavior research. It is a standardized sum of median household income, percentage of unemployed in the labour force, percentage of population that immigrated to Canada within the last five years, and percentage households spending over 30% of their income on rent. Because many socio-economic variables are highly correlated, the use of a combined indicator provides a more robust understanding of community deprivation and social equity issues beyond the single variable of income. In line with previous work, we anticipate that more socially disadvantaged TAZs will be associated with larger transit shares. In terms of job categories, this perhaps will be the least important for office/professional jobs as many (but not all) of these jobs likely have higher wages. Moreover, we test the 10% most socially disadvantaged TAZs and the 10% least socially disadvantaged TAZs and expect similar trends. The last variable in this group assesses whether the 10% most socially disadvantaged are likely to take transit more in 2006 than in 1996. As the socially disadvantaged areas are suburbanizing, we expect that transit may not be more influential in 2006.

The last group of variables measures the impact of transportation infrastructure in general, as well as whether new additions in 2006 led to significant changes in transit mode share. This includes subway stations, GO Train stations, and proximity to the new Highway 407 before and after. A 1000 m network buffer is used; this is based on a Canadian study which found that over 50% of people are willing to walk up to 900 m to reach a rapid transit station, but none farther than 1750 m (O'Sullivan & Morrall, 1996). We anticipate that the transit infrastructure additions in 2006 increase the likelihood to use transit. Last, a local bus frequency variable accounts for the effect of local bus service overall, as well as the difference between 1996 and 2006. We hypothesize that an increase of bus frequency corresponds with a greater transit share. A transit frequency variable is used as it can indicate a more realistic travel outcome than a count of stops or stations (Mavoa, Witten, & O'Sullivan, 2012).

5. Data

To assess changes in transit mode share over time by job category, datasets from several sources were collected. The statistical models' dependent variable, percentage of transit share for all jobs and three job categories, comes from the Transportation Tomorrow Survey (TTS) for 1996 and 2006 (University of Toronto, 1996, 2006). For this study, transit mode share includes buses, the subway, and the GO Train. The TTS is conducted by the University of Toronto and the survey collects travel behaviour information via telephone interviews every five years. We use 2001 Traffic Analysis Zone (TAZ) spatial definitions, with the 1996 and 2006 data matched to these shapefiles using a geographic information system (GIS). In the study area, there are 914 TAZs in 1996, with 21 added in 2001. Most of the newly divided TAZs are located in the City of Toronto. By nature of the survey, some of the TAZs in the study area have missing data; however mode share data for job categories is available for 736/914 TAZs in 1996 and 792/935 in 2006. The survey uses expansion factors to achieve data proportional to the TAZs' populations.

To calculate the gravity-based accessibility measures, 1996 and 2006 in-vehicle transit time is used (see Part 1 for calculating accessibility measures). To compare dataset, the TTS categories were matched to the 10 National Occupation Categories: office/professional (management, business/finance/administration, natural and applied sciences, health, education/law/social/community/government services, and art/culture/recreation/sport); manufacturing/construction/transport (trades/transport, natural resources/agriculture products, manufacturing/utilities); and retail/sales/service (sales/service). Summary statistics are presented in Table 2.

Table 2: Descriptive statistics for continuous variables.

	Mean		Standard deviation	
	1996	2006	1996	2006
Local bus (per hour)	66.2	59.7	65.3	58.5
Accessibility by transit to all jobs	71,359	76,778	19,318	27,718
Accessibility by transit to office/professional jobs	42,588	48,212	12,570	18,302
Accessibility by transit to retail/sales/service jobs	17,110	17,037	4,583	6,118
Accessibility by transit to manufacturing/ construction/transport	11,719	11,594	2,404	3,693

The social disadvantage indicator was generated using 1996 and 2006 census data at the census tract level (Statistics Canada, 1996, 2006). It was converted to the TAZ level for use in this study using a GIS. Where more than one census tract matched with one TAZ, census tract indicator values were weighted by population and summed. Since the social indicator data for 1996 and 2006 has different ranges, we use deciles (groups of 10% of the data) to test if a change in a TAZ's social disadvantage ranking corresponds with transit mode share.

The last group of data includes regional information about transport infrastructure and service in 1996 and 2006. The number of local buses per hour that pass through a TAZ during morning peak travel hours was provided by the University of Toronto (Data Management Group, 2006; El-Geneidy & Levinson, 2007). In addition, dummy variables capture whether a TAZ is close to subway stations and Highway 407. A 1000 m street network buffer was generated around the 1996 and 2006 subway stations using a GIS. Last, a 1000 m straight-line buffer was generated around Highway 407.

6. Findings

The findings section is divided into three parts. First, commuting trends are presented for the Toronto area in 1996 and 2006, including transit mode share and changes in accessibility to jobs by transit for all jobs, and the three job categories. Second, we describe how the statistical models were tested and finalized, and third, we explain the results of the regression analyses for the all jobs model, then the different job categories models.

6.1 Commuting trends

Although the region experienced changes including suburbanization of jobs and socially disadvantaged residential areas, as well as new subway stations, GO Train stations and a highway, the overall mode shares remained relatively constant. Between 1996 and 2006, there is ≤1% change in mode shares and automobile drivers continue to be the overwhelming majority (Table 3). The second largest group is commuters that take the bus and/or the subway to work (17.6% in 2006). The GO Train serves a relatively small percentage of commuters, and those who commute by GO Train make up the fewest of transit commuters. Aggregated transit mode share (subway, bus, and GO Train) shows an overall increase of 1.0% of commuters taking transit to work.

Table 3: Mode share by TAZs for study area, 1996 & 2006

Transport Mode	**1996**		**2006**		**Change**	
(to all jobs)	Sum	%	Sum	%	Sum	%
Auto driver	1,086,560	66.6%	1,254,831	66.2%	+168,271	-0.4%
Auto passenger	148,297	9.1%	160,009	8.4%	+11,712	-0.7%
Bus and/or subway	287,871	17.6%	336,510	17.7%	+48,639	+0.1%
GO Train (commuter rail)	23,477	1.4%	39,720	2.1%	+16,243	+0.7%
GO Train with bus/subway	8,642	0.5%	13,396	0.7%	+4,754	+0.2%
All transit (aggregated)	319,990	19.5%	389,626	20.5%	+69,636	+1.0%
Walk	58,285	3.6%	70,579	3.7%	+12,294	+0.1%
Cycle	12,592	0.8%	14,201	0.7%	+1,609	-0.1%

Table 4: Sum & average transit mode share by job category for study area TAZs, 1996 & 2006

Job Category	1996		2006		Change	
	Sum	%	Sum	%	Absolute	%
All jobs	301,436	22.2%	365,418	23.2%	+63,982	+1.1%
Office/professional	180,508	23.6%	214,132	26.2%	+33,624	+2.6%
Retail/sales/service	72,385	24.8%	119,351	24.0%	+46,966	-0.8%
Manufacturing/construction/transport	48,543	16.0%	31,935	12.4%	-16,608	-3.6%

When jobs are aggregated together, there is a moderate increase in the number of transit users, however, when job types are disaggregated, transit mode share varies quite notably (Table 4). For instance, the number of office/professional (office) workers more than doubles the number of workers in the manufacturing/construction/transport (trades) sector in both years. Over the 10-year period, there is a clear distinction between office workers patronizing transit more (+2.6%), and trades employees using transit less (-3.6%) to their respective job locations.

When the distribution of transit users is mapped, the percentage of transit commuters is not equally distributed throughout the region (Figure 7 & Figure 8). Suburban areas have far fewer transit users compared to TAZs in the City of Toronto. Interestingly, the only municipality around Toronto that has a relatively consistent transit share across the TAZs is Mississauga (west of downtown along the lake). This area had the first GO Train line, which may partly explain this outcome. The TAZs with highest percentages of transit users are clustered generally around downtown and the subway lines.

By job category, the distribution of transit users for all jobs closely resembles the office jobs distribution because this is the largest category of workers. Office commuters generally live closer to downtown, but are spread throughout the region. The retail/sales/service (retail) transit share maps share similar distributions. However, compared to the other job types, the trades job group has fewer TAZs with transit riders and the concentrations appear a little more distributed over the region.

Over time from 1996 to 2006, there is a general trend of greater transit mode share around the subway lines for all jobs in general. Nevertheless, the trades job maps show that concentrations of transit users seem fewer in 2006 than in 1996, which reflects the mode share trend. Furthermore, trades commuters seem to be moving away from the city centre, and the subway lines, over time.

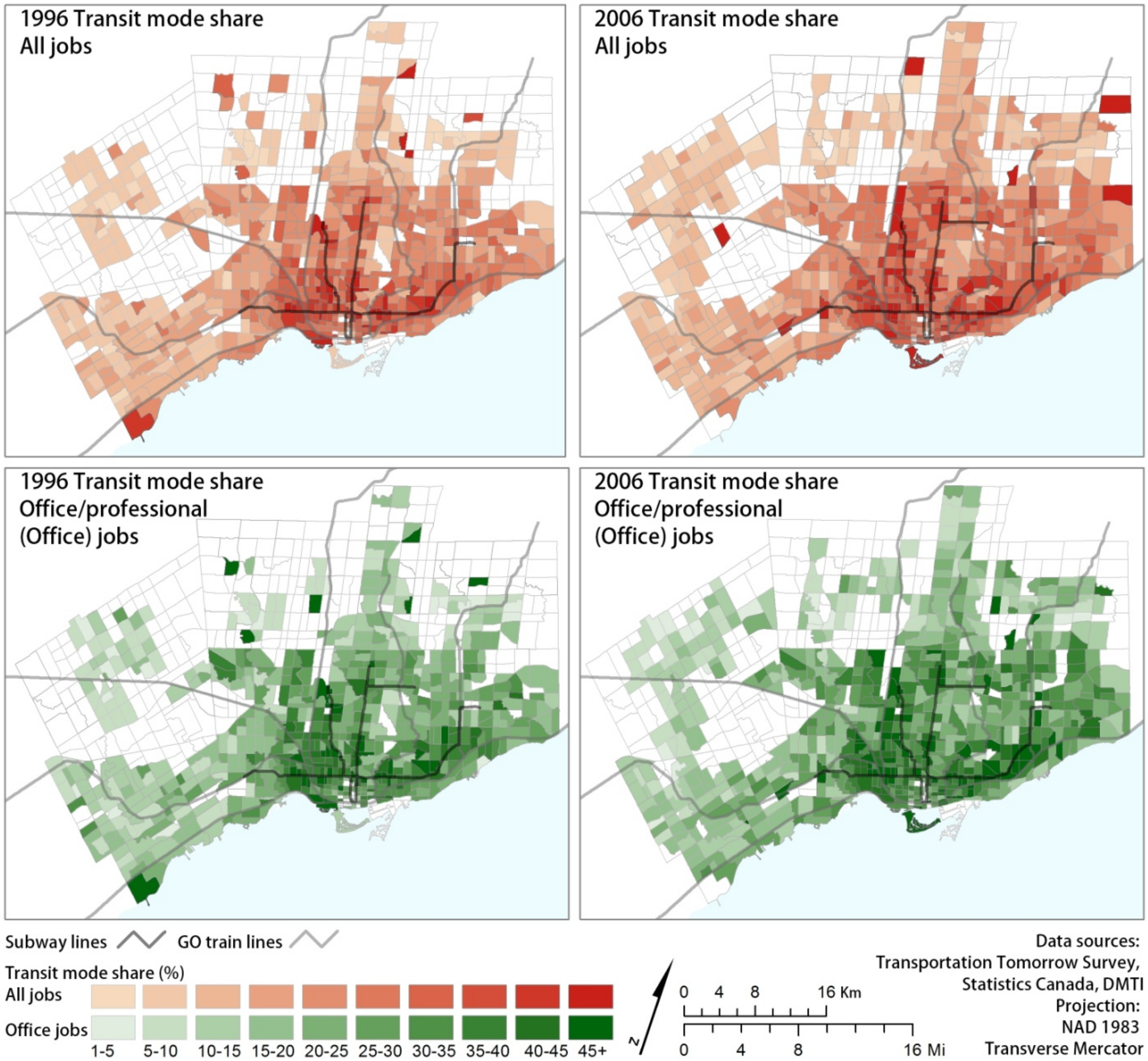

Figure 7: Percentage of transit mode share for all jobs & office/professional (office) jobs, 1996 & 2006

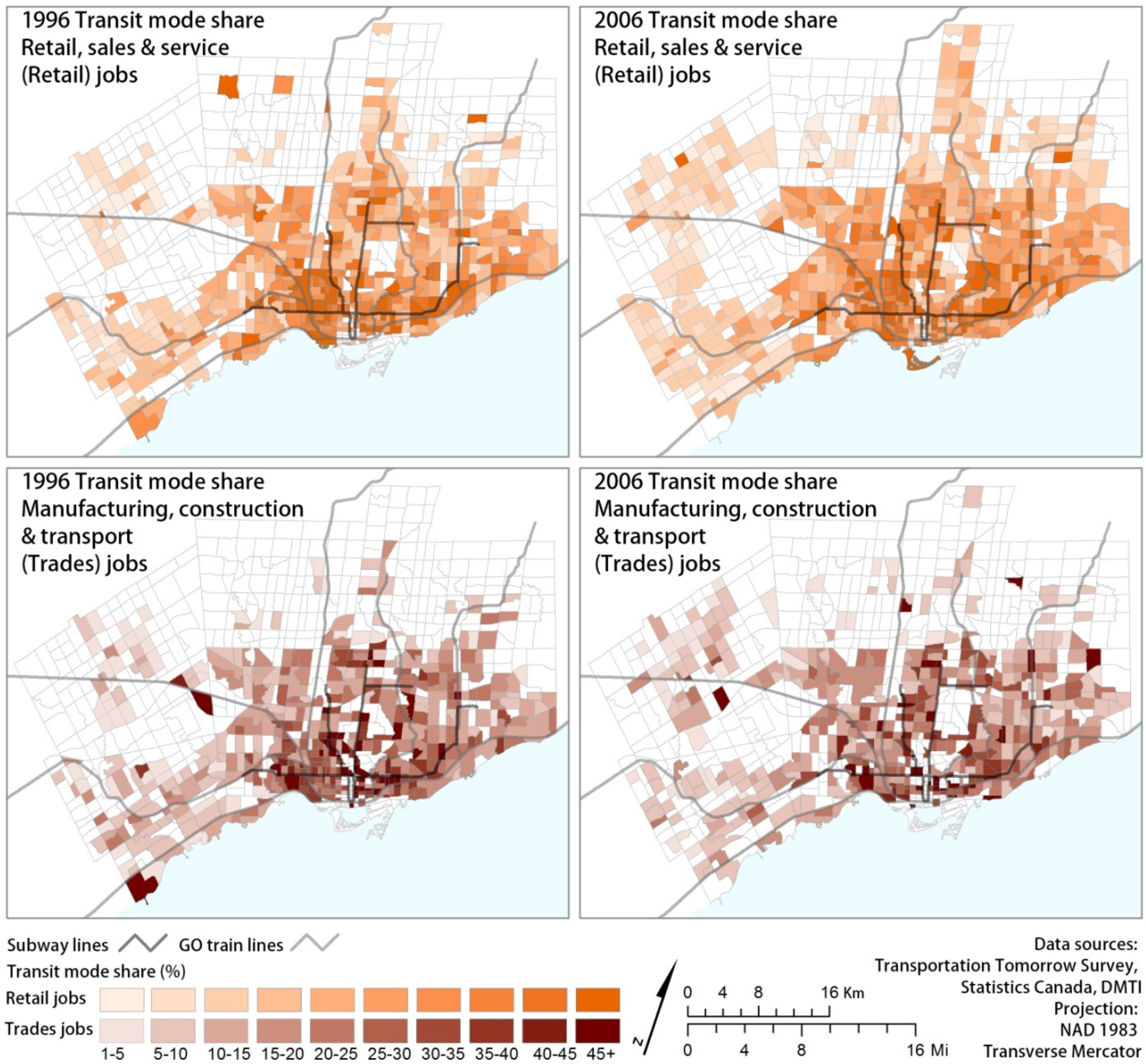

Figure 8: Percentage of transit mode share for retail/sales/service (retail) & manufacturing/ construction/transport (trades) jobs, 1996 & 2006

Accessibility measures capture accessibility to each job category via the transit network. Figure 9 and Figure 10 display accessibility to jobs by transit for each job category. Some TAZs do not have an accessibility value because there is no direct transit service, or there are no residences in these TAZs. All jobs, office and retail jobs have a similar distribution, and accessibility expands around the subway from 1996 to 2006. In contrast, trades job accessibility shifts from roughly surrounding the subway in 1996 to the northwest, away from downtown and the subway lines in 2006. These trends are reflected in the previous transit mode share maps.

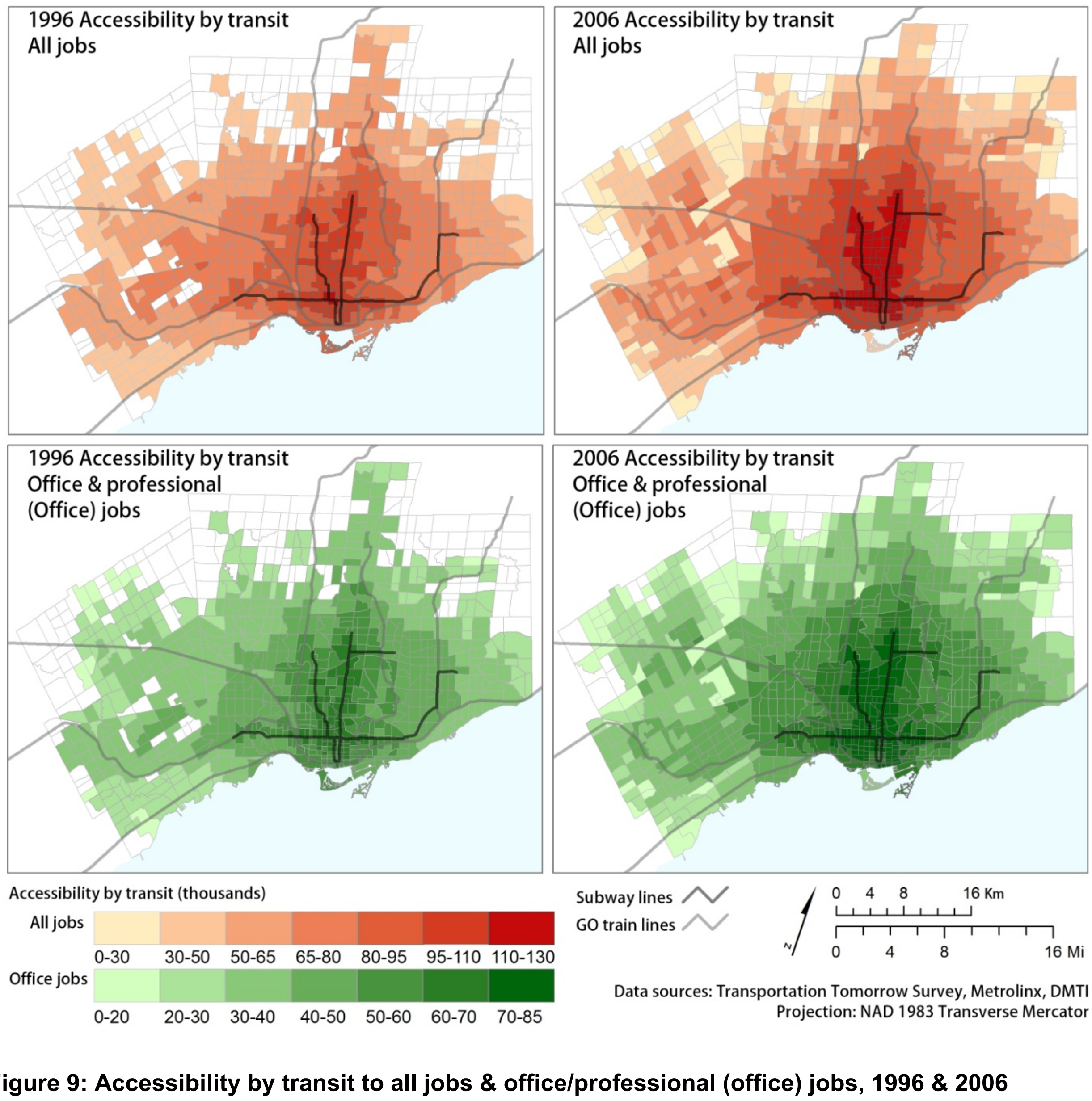

Figure 9: Accessibility by transit to all jobs & office/professional (office) jobs, 1996 & 2006

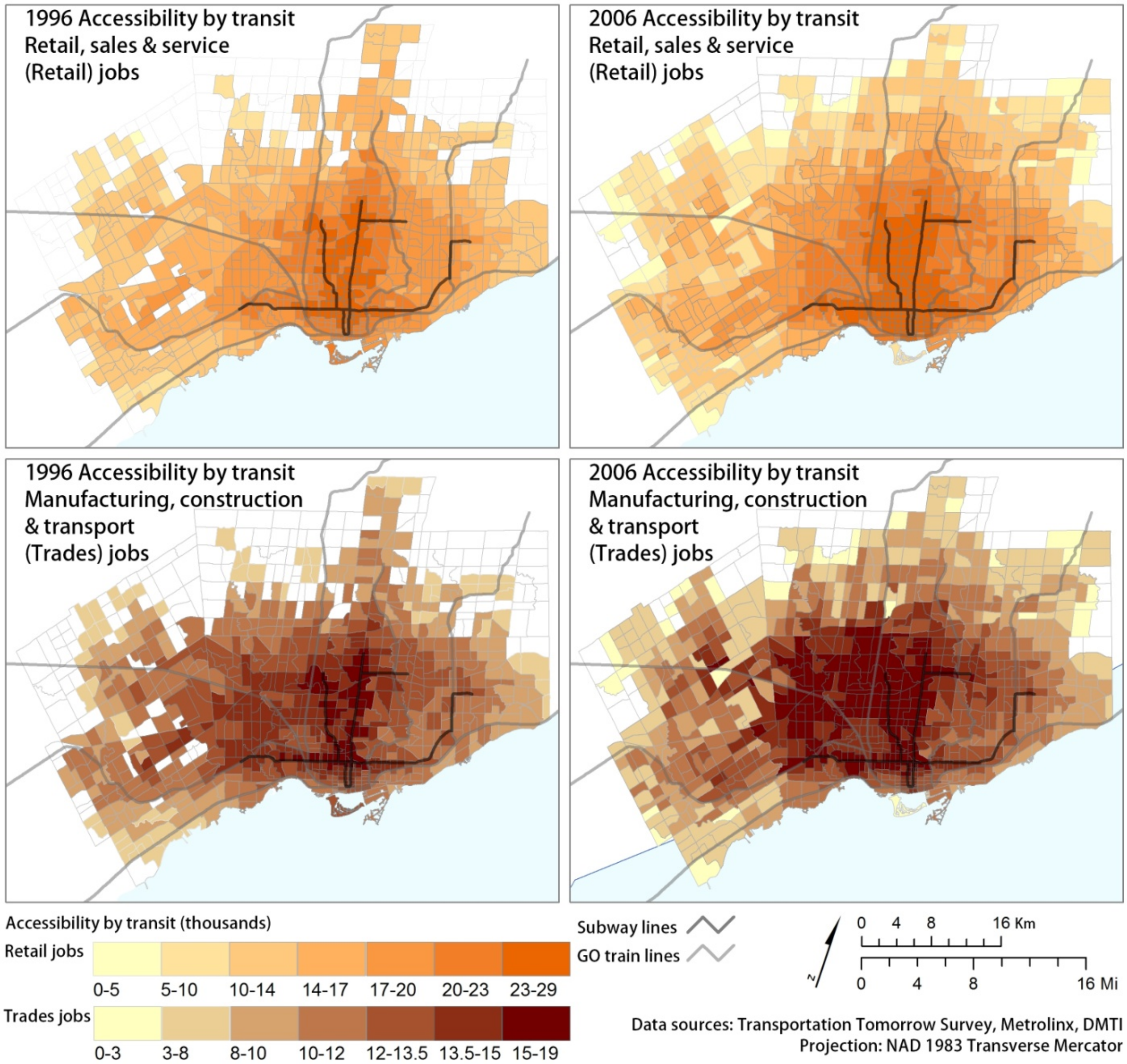

Figure 10: Accessibility by transit to retail/sales/service (retail) jobs & manufacturing/ construction/transport (trades) jobs, 1996 & 2006

6.2 Regression findings & discussion

We found that several variables explain transit mode share with statistical significance, and that the job category models provide more precise explanations of transit mode share than the general aggregate job model. The regression outputs confirm that accessibility, social disadvantage, transport networks, and time (a year dummy and interaction variables) explain general changes in transit mode share between 1996 and 2006. Table 5 displays findings for the all jobs model and the three job category models with statistically significant variables level noted. First, the all jobs model is discussed, then the three job type models are explored by highlighting similarities and differences.

We tested a correlation matrix of the independent variables of the all jobs category. The matrix shows that the variables do not pass the highly correlated mark of 0.7 (Kuby, Barrada, & Upchurch, 2004). A few variables have a correlation higher than 0.5. Subway, and subway and 2006 interaction, are related to some extent (0.67), which is to be expected as the interaction variable contains half of the subway variable's data. The accessibility by transit variables are related to subway (0.51 to 0.59) since the accessibility measures use the subway network. Last, the social disadvantage indicator slightly correlates with the most socially disadvantaged TAZs and accessibility interaction variable (0.51).

6.2.1 All jobs model

All statistically significant variables in the all jobs model are at the 99% confidence level. The year 2006 dummy variable is statistically significant, which indicates that people took transit 1.7% more in 2006 compared to 1996. This variable shows that there are other explanations for a growing transit mode share in the all jobs model, holding the transport network and socio-economic factors constant at their mean values. The increase may point to a growing 'transit culture' where individual attitudes and personal values determine mode choice and location decisions. Exploration of disaggregate attitudes is beyond the scope of this study, but the significance of the more recent year explaining transit mode choice beyond built environment and socio-economics is an interesting observation.

Several network and infrastructure variables are noteworthy and point to the role of transit service and land use. The frequency of local buses has a statistically significant and positive effect on transit mode share to work for all jobs; an addition of 100 buses passing through a TAZ corresponds with a 2.0% increase in transit use. However, the subway is visibly the spine of the Toronto transit system. This variable is statistically significant and exhibits the largest coefficient in the all jobs model: TAZs within 1000 m of a subway station in either year are likely to have 7.7% higher transit mode share compared to other TAZs in the region. This variable supports previous research and our hypothesis that transit proximity at residential origins is a notable predictor of higher transit mode shares (Bento et al., 2005; Ewing & Cervero, 2010; Lin & Long, 2008; Moniruzzaman & Páez, 2012), even while controlling for socio-economic characteristics and job accessibility.

Table 5: Regression results

	All jobs		Office, Professional		Retail, Sales, Service		Manufacturing, Construction, Transport	
	β	t-stat	β	t-stat	β	t-stat	β	t-stat
[constant]	-0.013	-1.639	0.010	0.984	-0.033**	-2.555	-0.022*	-1.691
Year 2006	0.017***	2.720	0.019**	2.464	0.011	1.204	-0.004	-0.407
Local bus frequency (hundred)	0.020***	4.236	0.027***	4.742	0.021***	3.047	0.010	1.464
Subway station	0.077***	8.441	0.061***	5.496	0.059***	4.374	0.113***	8.890
Subway station*2006	-0.019	-1.623	-0.015	-1.084	-0.020	-1.206	-0.067***	-4.011
Highway 407*2006	-0.036***	-2.936	-0.041***	-2.650	-0.047**	-2.503	-0.038**	-2.101
Social disadvantage indicator (by decile)	0.011***	10.400	0.012***	8.691	0.016***	10.271	0.014***	8.926
Accessibility by transit to all jobs (ten thousand)	0.016***	13.757						
Most disadvantaged (decile 1) *Accessibility by transit to all jobs	0.003***	2.797						
Accessibility by transit to office/ professional jobs (ten thousand)			0.026***	11.072				
Most disadvantaged (decile 1) *Accessibility by transit to office/professional jobs			0.003	1.542				
Accessibility by transit to retail/sales/ service jobs (ten thousand)					0.077***	9.539		
Most disadvantaged (decile 1) *Accessibility by transit to retail/sales/service jobs					0.012	1.833		
Accessibility by transit to manufacturing/ construction/transport jobs (ten thousand)							0.044***	3.636
Most disadvantaged (decile 1) *Accessibility by transit to manufacturing/construction/transport jobs							0.032***	3.246
	$R^2 = 0.52$		$R^2 = 0.41$		$R^2 = 0.37$		$R^2 = 0.27$	

Dependent variable: transit percentage of mode share by job type (each model) Confidence levels: *** 99% ** 95% * 90%

Although the subway is a statistically significant predictor of transit share, the interaction variable of subway and 2006 shows how the new Sheppard subway line, opened in 2002, does not explain transit share more in 2006 than 1996, and in fact the coefficient is negative (it is important to note that four stations were added, which only affects a small sample of all TAZs in the study area). This demonstrates that these stations did not alter transit mode share in the TAZs in close proximity to them, and is counter to our hypothesis. Here the axiom 'build it and they will come' does not seem to materialize. However, there may be several years of lag in the change of land use patterns to adjust to the new subway line. Thus, this deserves further evaluation to determine the long-term changes around these subway stations. Nevertheless, we kept this variable in the all jobs model because it shows a statistically significant impact on some job categories discussed in the next section.

While the location of transit infrastructure may provide transit benefits to some, other infrastructure has an adverse effect on transit mode share. In 2006, after the construction of Highway 407, commuters residing in TAZs within 1000 m of the new highway are 3.6% less likely to commute by transit compared to other TAZs in the region. The same TAZs were tested in 1996 before the highway was completed and none of the models displayed statistical significance. Thus, construction of Highway 407 corresponds with a decrease in transit mode share. As we anticipated, the regression results confirm that the construction of Highway 407 has an observable negative impact: expanding car infrastructure will make increasing transit ridership difficult. These results echo Kawabata's (2009) finding that proximity to highways increased disparity between accessibility by transit and by car, over a 10-year period. Several other transport infrastructure and service variables were tested and subsequently dropped from the regression analyses, including GO Train stations and its 2006 interaction variable, and the local bus 2006 interaction variable. These variables did not affect transit mode share.

One group that is likely to take transit more is the socially disadvantaged. This finding is statistically significant for the all jobs model: transit share is predicted to increase by 1.1% for each decile increase of social disadvantage, at the 99% confidence interval. This is of particular interest considering the other independent variables in the model: by holding transport service and infrastructure variables constant, as well as accessibility by transit, socio-economic factors alone predict greater transit mode share. Results from the social disadvantage indicator support previous research that socio-economic status does matter for mode choice; specifically, more socially disadvantaged areas rely on transit more. The decile of least socially disadvantaged TAZs did not show an impact on transit mode share and was dropped from the model.

Accessibility to all jobs by transit is positive and statistically significant. An increase of accessibility by transit by 10,000 jobs in general is associated with a 1.6% increase in transit share, a coefficient similar to but greater than Moniruzzaman & Páez (2012) (+0.2 to +0.5% per 10,000 jobs). This means that when commuters in an area can reach more destinations, either via a good transit network or a clustering of destinations, these travellers are more likely to use transit. Therefore, accessibility is an important predictor of transit use. This supports our hypothesis, as well as the growing body of literature that finds accessibility is an important predictor of mode selection. Thus, it should be considered in the bundle of performance measures to evaluate projects trying to increase transit mode share. We also tested accessibility to jobs by car, however it was collinear with accessibility by transit and therefore we excluded it from the model. The interaction variable of accessibility to jobs by transit in 2006 did not show an impact on transit mode share and was dropped from the model. This indicates that accessibility had a consistent effect on commuter transit mode share from 1996 to 2006.

An interaction variable that is statistically significant is accessibility by transit to jobs multiplied by the most socially disadvantaged decile. The results for the all jobs model show that if a TAZ is in the most socially disadvantaged decile, then an increase in accessibility by 10,000 jobs raises the likelihood to take transit by 0.3%—in addition to the 1.6% increase of the accessibility variable above. This variable demonstrates that the most socially disadvantaged TAZs respond to an increase in accessibility even more than other commuters, and it supports our hypothesis. Moreover, this variable shows more interesting results when job types are disaggregated. We selected this interaction variable as it produced more significant results than the most socially disadvantaged decile variable on its own. Since these two variables showed multicollinearity, the most socially disadvantaged decile variable was excluded from the model.

6.2.2 Job category models

When analyzing the job category models, some variables have similar results as the all jobs model, such as Highway 407 and the social indicator variables. Finding that the social disadvantage indicator is statistically significant for all job categories supports its use in transport studies. Furthermore, this highlights the need for social equity planning as these groups rely more on public transport, especially as the most socially disadvantaged areas in Toronto are suburbanizing. These variables appear to be relevant for everyone and affect all commuters alike.

At the same time, there are a number of differences between the job category models and the aggregated jobs model that tell a more nuanced story about transit mode share. In comparison to the R-squared value for the all jobs model (0.52), the R-squared values in the job category models are slightly lower (office 0.41, retail 0.37, and trades 0.27). This means that 27% to 41% of the variation in the transit mode share for each job category can be explained by the independent variables. For the dummy year 2006 variable, the job category models make it clear that this is statistically significant only for the office/professional (office) jobs category, with a 1.9% increase in the likelihood to commute by transit in 2006 at the 95% confidence interval. This suggests that perhaps a more sizable 'transit culture' exists for office workers. The retail/sales/service (retail) and manufacturing/construction/transport (trades) job models show marginal impact for the 2006 variable.

Turning to the influence of infrastructure and transit networks on the transit percentage of mode share, an addition of 100 local buses in a TAZ is statistically significant at the 99% confidence level for the job categories office (2.7%) and retail (2.1%), but not for trades jobs. Nonetheless, these findings are modest compared to the predictive power of subway stations. For all models, living within 1000 m of a subway station is positive and statistically significant at the 99% confidence level. For proximity to subway stations, the trades job model clearly demonstrates the largest coefficient in this study: an 11.3%

increase in the likelihood for trades workers to take transit to trades jobs if living within 1000 m of a subway station. Subway station proximity for other job categories is also a relatively strong predictor of transit share (office at 6.1% and retail at 5.9%). However, this range of findings among job categories is diluted in the all jobs model (7.7%). Overall, trades workers in TAZs near subway stations are almost twice as likely to take transit to work compared to the retail jobs group. This demonstrates that some job categories are more likely to respond to transit infrastructure than others, which is a particularly interesting finding because there is a decline in transit mode share for the trades category. However, it is more likely due to changes in land use as trades jobs are moving away from the subway line and downtown areas, and part of an overall employment suburbanization trend. This presents a challenge to future transit planning in the Toronto region, although this trend is not unique to Toronto. Some hope that with increased transit service falling transit mode shares can be slowed or reversed (Brown & Thompson, 2008).

The interaction variable of subway and 2006 is only statistically significant in the trades jobs model, and it is negative. In other words, workers with trades jobs that are in proximity of a new Sheppard line subway station in 2006 correspond with a 6.7% *decrease* in transit share, at the 99% confidence level. Clearly, compared to the other job categories, the Sheppard subway stations do not serve trades workers trying to commute to skills-matched jobs. The map illustrating accessibility to trades jobs in the previous section (Figure 10) confirms that the concentrations of trades jobs are not well-served by the Sheppard subway. Transit infrastructure decisions should strive to account for the needs of commuters in various socio-economic situations and the destinations they desire to reach. In contrast to the effect of subways on transit mode share, construction of Highway 407 shows that it is statistically significant and it negatively affects all job models in a similar way: office at -4.1% at the 99% confidence level, and retail at -4.7% and trades at -3.8% at the 95% confidence level. These coefficients show similar magnitudes to the all jobs model (-3.6%). Thus, opening the highway impedes transit mode share regardless of job category.

The most interesting difference between the all jobs and job category models is the accessibility by transit variable. The coefficient for accessibility to jobs by transit varies notably when job categories are explored. Interestingly, accessibility by transit to skills-matched jobs is a much stronger predictor of transit use than jobs in general (1.6%). This is because an increase of accessibility to skills-matched jobs is much more valuable to a worker than jobs in general. All the accessibility variables in the job type models show statistical significance at the 99% confidence level. The retail job category has the largest coefficient where an increase of accessibility by transit by 10,000 retail jobs is associated with a 7.7% increase in transit share, office workers by 2.6%, and trades jobs by 4.4%. The findings support our hypothesis that accessibility's effect on transit mode share does vary by job category, although we did not expect the retail job category to show the largest coefficient. By locating future retail jobs near transit hubs, these workers may be the most inclined to take transit to their jobs.

The fact that accessibility by transit increases transit mode share for trades jobs is somewhat surprising as transit use by workers with trades jobs declined 3.6% (-16,608) from 1996 to 2006. However, the accessibility maps presented earlier indicate that these jobs are clustered away from the subway lines and the downtown core. Thus, declining transit mode share in the trades job category shows that it is not necessarily because this group of workers does not want to use transit, but the locations of their jobs are not near the bulk of regional transit services. In other words, the negative transit modal trend is likely due to land use and (re)locations of work, rather than the desire of trades workers to avoid transit. Thus, the results indicate that there is variation by job types, and the all jobs model can at times temper the explanatory variables of transit mode share for different job categories.

Finally, the interaction variable of accessibility by transit and most socially disadvantaged TAZs demonstrates that some socially disadvantaged workers respond to increases in accessibility more than others. This variable demonstrates how accessibility to jobs affects the decile of most socially disadvantaged workers in particular. Of the job category models, only the trades job model is statistically significant, and at the 99% confidence level. This shows that the most socially disadvantaged workers with trades jobs are 3.2% more likely to take transit with an increase in accessibility by 10,000 skills-matched jobs compared to less socially disadvantaged workers. For social disadvantage deciles in general, each decile increase of social disadvantage corresponds with an increase in transit use (office at 1.2%, retail at 1.6%, and trades at 1.4%). This demonstrates that social disadvantage affects all jobs and all job categories similarly. These results are all statistically significant at the 99% confidence level.

7. Conclusion

This study presents new findings to support the use of disaggregate job categories and change over time in mode share research. Using data at the Traffic Analysis Zone (TAZ) level, job type models provide new explanations of transit mode share that is not evident in the all jobs model. This is because aggregating job types dilutes some noteworthy differences between the transit mode choices of job categories. For accessibility by transit, an increase in accessibility to jobs in general positively corresponds to a larger transit mode share. Nonetheless, increasing accessibility by transit to skills-matched jobs raises the likelihood of taking transit to work considerably more. We found that retail/sales/service workers are most likely to commute by transit with an increase in accessibility to skills-matched jobs by transit. This finding suggests that by increasing accessibility, either through superior transit networks or concentration of desired destinations, some job categories are more likely than others to commute by transit.

Findings for social disadvantage demonstrate the importance of social equity goals in transportation planning. Increasing social disadvantage correlates with increased transit shares and affects all workers similarly, irrespective of job category. Moreover, with an increase of accessibility for the 10% most socially disadvantaged areas, manufacturing/construction/transport workers are likely take transit even more. This finding highlights the importance of using accessibility as a performance measure when evaluating infrastructure projects that aim at increasing transit mode share among socially disadvantaged populations. In terms of transport infrastructure, the presence of subway stations in either year is a predictor of transit mode share. Yet, we find that new subway stations do not necessarily increase transit mode share for certain job categories, such as manufacturing/construction/transport; this occupational group does not benefit from the new transit infrastructure. This can be mainly related to the location of the new subway projects and its relation to the distribution of jobs in the region. Last, new highway infrastructure considerably impedes transit mode share for all commuters, regardless of job type.

Results from this study show that while changes in transit infrastructure affect workers across job categories, some job types differ in their response to the same variables. These variations add to the complexity of commuting travel behaviour, and contribute to the body of mode share research. The methodology presented in this study would be of interest to land use and transportation planners who seek to boost transit ridership in their regions.

7.1 Limitations & Future Research

There are a few limitations in this study. First, results at the TAZ level are not intended to be interpreted for the individuals in each TAZ in order to prevent ecological fallacy (aggregate level relationships do not necessarily hold true at the individual level) (Handy, Boarnet, Ewing, & Killingsworth, 2002). Second, because the general office and professional/technical job categories from the TTS data were combined, these findings should be interpreted with some caution. Finally, this study does not control for residential self-selection as this data was not available in the survey. This may lead to a slight decrease in the coefficients' magnitude, but the trends are likely to be the same. Adding residential self-selection questions to travel surveys would provide opportunities for interesting future research. Although conclusions from context-specific studies should not be simply imported to another context, these findings would help transportation researchers and planning practitioners understand that the determinants of transit mode share vary by job category, and how changes in a region affect transit use over time.

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Project Conclusion

Part 1 and Part 2 contribute a further understanding of commuting trends and patterns in the Toronto area from 1996 to 2006. Part 1 focuses on the accessibility and travel time to jobs via the transit system for socially disadvantaged areas in the region. This research creates a social indicator useful for transportation studies. While social indicators have been used in health studies for several decades, they seldom have been applied to transportation research. Thus, the methodology outlined in Part 1 offers a way to bring social equity issues into the land use and transportation planning process. The conclusion of the study is that Toronto has a generally equitable transit system as it benefits commuters in socially disadvantaged census tracts. These commuters represent transit users who are likely to gain the most from transit because their choices of other transportation modes may be constrained. The system is considered equitable because the range in accessibility and transit travel time narrows from 1996 to 2006. Furthermore, the decile (10%) of the most socially disadvantaged census tracts have statistically significantly better accessibility and lower transit travel times relative to the region in both years. Nevertheless, there is a trend of suburbanization of the most disadvantaged census tracts from 1996 to 2006. This suburbanization process points to social equity concerns for the future as suburban locations typically have lower levels of transit service than central city areas. Thus, while Toronto's transit system currently serves socially disadvantaged commuters, it will be important to monitor the spatial patterns of socially disadvantaged areas in the future.

Part 2 expands the mode share research field by offering new insight about the importance of disaggregating job categories. This part assesses transit mode share over time by evaluating how changes in the transport system affect transit mode share. Findings include that most variables remain consistent over time in explaining transit mode share, such as social disadvantage, and accessibility to jobs by transit. Further, increasing accessibility by transit to skills-matched jobs is a much stronger predictor of transit use than general jobs. Moreover, workers in the most socially disadvantaged decile are more likely to take transit with an increase in accessibility, especially for manufacturing/construction/transport jobs in this case. Proximity to transit infrastructure is also important, and certain job categories may respond to these changes more than others, in this case retail/sales/service jobs. Highway construction has a negative impact on transit mode share, while new transit infrastructure may not benefit certain workers if it does not link origins and desired destination, especially when certain jobs are moving away from major transit infrastructure, such as with manufacturing/construction/transport jobs. The findings reveal the value of disaggregating job types for more nuanced mode share research. Overall, this research project presents ways to incorporate issues of social equity in the land use and transportation planning process, and it demonstrates the benefit of including commuting trends by job category in transportation research and planning.


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