ASSESSING ACCESSIBILITY: THE EFFECTS OF ACCESSIBILITY IMPROVEMENTS ON NEIGHBOURHOOD DEVELOPMENT

SUPERVISED RESEARCH PROJECT | ROBBIN DEBOOSERE

Assessing accessibility: The effects of accessibility improvements on neighbourhood development

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Transport and land use are inextricably linked. Growth occurs where transport infrastructure is constructed, and transport investments are made where land use is changing. Yet current planning documents tend to isolate transport by solely focusing on mobility, or how fast we can travel, while disregarding the destinations we want to reach.

To combat this flawed planning paradigm, accessibility indicators are increasingly being used in both research and practice. Accessibility improves upon the concept of mobility by also considering potential and desirable destinations, instead of only examining our ability to move through the transport network. The most common accessibility indicator measures the number of jobs that can be reached within a certain time threshold. Accessibility thus recognizes that most of us travel not for its own sake, but to reach a destination.

While cities such as London, Paris, and Sydney are now employing the concept in their transport plans, Canadian cities are lagging far behind and are missing out on the myriad of benefits unlocked by accessibility planning. To quantify these benefits, this study has examined both the social and economic effects of accessibility improvements on neighbourhood development.

Neighbourhood benefits of accessibility

Apart from the direct transport benefits, policies aimed at improving accessibility can help Canada's neighbourhoods in the following five ways:

1. Increases in accessibility are related to **increases in household income**. The most vulnerable census tracts in Toronto where accessibility improved saw their income increase by $3,000 more than similar areas where accessibility remained stable.[†]

2. Accessibility improvements are associated with relative **decreases in unemployment rates**. The most vulnerable census tracts in Toronto where accessibility improved saw their unemployment rate rise by 1% less than similar areas where accessibility remained stable.[†]

3. Higher accessibility to jobs results in **shorter commutes**. If the average accessibility level in Toronto would be doubled, commute times would decrease by 2.12 minutes.
4. High accessibility locations attract **more** residential, commercial, and industrial **development**. If average accessibility to workers in Toronto would be doubled, each neighbourhood would attract 44 extra jobs per square kilometer.
5. **Transit modal share is higher** in high accessibility neighbourhoods. For every 100,000 jobs accessible by public transport, transit modal share increases by 4.25% (up to 6.21% in socially vulnerable areas).

What should policy makers do?

Here is how Canadian cities can seize the opportunity to be the world leaders in innovative accessibility planning:

1. **Incorporate accessibility into transport planning documents**. By using explicit accessibility objectives to reach planning goals, each decision will be based on a comprehensive understanding of the transport and land use interaction.
2. **Evaluate transport investments through accessibility.** Consider which areas will see their accessibility levels improve from the investment, and thereby also their income, unemployment rates, commutes, economic development, and transit mode share. Planners can thus use accessibility to foster socially inclusive environments that are also conducive to development.
3. **Monitor progress of key planning goals and objectives through accessibility indicators.**

Through these recommendations, Canadian cities can move away from the outdated mobility planning paradigm and instead utilize accessibility-oriented development techniques, and thereby maximize the benefits resulting from their transport investments.

[†] For every one unit increase in a competitive accessibility metric, which takes into account competition for jobs

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INTRODUCTION

> "It is clear that transport is a main factor in all large-scale town-planning. The arrangements of houses must always have a direct relation to the daily movements of the inhabitants. […] Town-building and transport are two elements in one problem that ought never to be separated. […] There can be no good regional planning in London or anywhere else unless the location and the movement of population are treated as one problem." (The Spectator, 1933)

The concept of integrated land use and transport planning was not a new idea. In 19th century London, urban thinkers had already recognized the inherent connection between transport and land use. In 1846, Charles Pearson advocated the joint development of both railways and housing estates, while other reformers in Victorian London recognized similar opportunities and encouraged the construction of railways to disperse London's ever-growing population (Barker & Robbins, 1963; Dyos, 1955; Haywood, 1997). Even in the unregulated, laissez-faire climate enjoyed by railways at the time, residential growth occurred where railways were constructed; similar mechanisms were at play in the railroad towns of the North American hinterland, the expansion of Berlin, or Boston's streetcar suburbs (Ahlfeldt & Wendland, 2011; Sultana, 2017; Warner, 1962).

Similar calls to action, advocating an integrated view on land use and transport planning, were issued *en masse* in the 1960s (see, for example, W. Owen (1966) and Mumford (1968)). Yet mobility planning, which had gained traction by traffic engineers in the 1950s and 1960s due to the dominance of the private automobile, was the prevailing paradigm at the time: transport was isolated from land use (P. W. G. Newman & Kenworthy, 1996). Endless suburban sprawl resulted.

In the last few decades, planners, increasingly concerned with traffic congestion, sprawl and environmental degradation, have slowly started to shift away from the concept of mobility planning towards accessibility planning – a shift accelerated by Calthorpe's transit-oriented developments and the New Urbanism movement (Calthorpe, 1993; Cervero, 1997; Congress for the New Urbanism, 1999; P. W. G. Newman & Kenworthy, 1996). The accessibility planning paradigm intends to revalorize the land use and transport connection, while re-focusing planning on people and away from the automobile (Cervero, 1997).

Accessibility, or the ease of reaching destinations, is now increasingly being used in both research and practice as a key performance indicator for the accessibility planning paradigm (Boisjoly & El-Geneidy, 2017b; D. G. Proffitt et al., 2017). Accessibility, usually operationalized as the number of opportunities (such as jobs or schools) an individual can reach within a certain time threshold, improves upon the concept of mobility by also considering potential and desirable destinations, instead of only examining an individual's ability to move through the transportation network. As such, accessibility to destinations explicitly considers the connection between land use and transportation (Geurs & van Wee, 2004; Handy & Niemeier, 1997; Hansen, 1959; Wickstrom, 1971).

Metropolitan transport plans, such as those in London, Paris, Sydney, and Atlanta, are now increasingly employing the concept of accessibility, either as an independent goal or objective, or as part of an environmental justice assessment (Atlanta Regional Commission, 2016; Conseil régional d'Île-de-France, 2014; NSW Government, 2012; San Diego Association of Governments, 2011; Transport for London, 2006). Authors of these transport plans argue that increasing access to opportunities can reduce social disadvantage while at the same time acting as a catalyst for economic growth. The plan for Sydney, for example, mentions supporting regional development by improving accessibility to jobs, while in London improved access to employment is used as a proxy for social inclusion (NSW Government, 2012; Transport for London, 2006).

Yet despite these hypothesised benefits, planners across Canada have been slow to adopt the concept. Montréal's 2008 transportation plan mentions the term vaguely, but does not include it as an objective or goal (Ville de Montréal, 2008). In Toronto, the 2008 Big Move issued by Metrolinx only provides a crude indicator for accessibility to public transport, and not to potential destinations (Metrolinx, 2008). Only the 2016 discussion paper includes accessibility to jobs, services and major destinations as an objective, and provides accessibility maps (Metrolinx, 2016). In contrast, Vancouver's 2014 transport plan does not even mention accessibility to destinations (Mayor's Council on Regional Transportation, 2014).

The transport plan for Calgary incorporates accessibility to the transit network, accessibility to daily needs and accessibility to major destinations, but defines the concept vaguely as the "ease of access/egress to any location by walking, cycling, transit, and private vehicles, or for commercial vehicles" (The City of Calgary, 2009). Edmonton's transport plan mentions accessibility to employment opportunities, but only in the context of complete communities (City of Edmonton, 2009). Similarly, the plan for Ottawa focuses only on access to transit stations and not to destinations, although some transit priority investments are rationalized through accessibility to employment (City of Ottawa, 2013). Thus, among major Canadian metropolitan areas, only Toronto is in the process of adopting accessibility to destinations as a key performance indicator. In particular, Metrolinx aims to improve access to employment and other opportunities for vulnerable populations, mirroring similar policies in London and Sydney aimed at creating economic growth and reducing inequality.

To increase the uptake of accessibility planning among Canadian cities, the benefits of such an approach should be more carefully examined: what can cities gain from adopting accessibility planning and indicators? What could be the benefits of policies aimed at improving accessibility levels? Only when planners are aware of these effects can they start to adopt the concept of accessibility to guide planning policies in their city.

However, while a large body of literature has assessed accessibility levels for different cities, socio-economic groups and neighbourhoods, or changes in these accessibility levels over time, little research has been conducted to assess the outcomes of improvements in accessibility: what will occur to neighbourhoods of different socio-economic status when accessibility levels change? Can government policies, such as those in Sydney, London and Toronto, targeting accessibility improvements in socially deprived neighbourhoods, help residents living in these areas? And can accessibility improvements provide a catalyst for economic growth?

This supervised research project examines the impacts of changes in accessibility levels on neighbourhood development. The first chapter provides a comprehensive look at **the state of accessibility** in Canada's largest cities and compares these cities in terms of the equity of their transport and land use systems. In the second chapter, the **social benefits** of accessibility changes are investigated, while the third and final chapter presents a study on the **economic benefits** occurring from changes in accessibility levels. Both chapter two and three focus on the context of the Greater Toronto and Hamilton Area, Canada's largest metropolis, housing around seven million inhabitants. Social benefits are measured through changes in neighbourhood median income and unemployment rates, while economic benefits are measured through residential and job density.

CHAPTER 1: EVALUATING ACCESSIBILITY TO LOW-INCOME JOBS ACROSS CANADA[1]

Transport and land use planning are inextricably linked. Although the modern concept of integrated transport and land use planning goes back to at least the 1930s (one could even argue as far back as 1846 when Charles Pearson suggested coupling housing estates and railway stations in London), interest seems to have been renewed after Calthorpe's proposal advocating transit-oriented developments and the rise of the New Urbanism movement (Barker & Robbins, 1963; Calthorpe, 1993; The Spectator, 1933). Since, transport planners have started to move away from the dominant mobility planning paradigm, which had gained traction by traffic engineers in the 1950s and 1960s due to the dominance of the private automobile, towards the concept of accessibility planning (D. G. Proffitt et al., 2017).

Accessibility, or the ease of reaching destinations, is now being increasingly used to operationalize notions of integrated land use and transport planning and to act as a performance indicator for these concepts (Boisjoly & El-Geneidy, 2017b). Indeed, metropolitan transportation plans, such as those in London, Paris, Sydney and Atlanta, are now employing the concept, either as an independent goal or objective, or as part of an environmental justice assessment (Atlanta Regional Commission, 2016; Conseil régional d'Île-de-France, 2014; NSW Government, 2012; Transport for London, 2006).

Starting with Hansen (1959) (and somewhat later Wickstrom (1971), Ingram (1971) and Dalvi and Martin (1976), among others), a growing body of literature has been continuously refining the concept of accessibility. By far the most widely used metric for accessibility is the number of jobs an individual can reach within a set time limit (known as a cumulative opportunity measure). One of the inherent strengths of this measure is that it makes comparisons between different socio-

[1] Co-authored with Ahmed El-Geneidy

economic groups fairly straightforward. It is thus not surprising that accessibility, especially in literature focusing on equity concerns, has often been used to identify which groups are being well served, and which are being underserved, or to predict who will benefit from a new transport or land use project. Contemporary research, however, relies on accessibility to jobs metrics that lack the ability to accurately discern between distinct populations; all jobs are usually counted as being accessible for everyone, as long as they can be reached.

This study refines the accessibility to jobs concept by developing a measure of accessibility to low-income jobs for vulnerable residents by public transport. Such a metric has the advantage of specifically considering the opportunities that can be accessed by vulnerable groups, instead of grouping together e.g. finance and manufacturing jobs and assuming that these can be filled by everyone. Furthermore, the metric employs realized public transport travel times by low-income groups to correctly reflect the different characteristics between mode choice and commutes by different socio-economic populations. The finer granularity of this metric allows planners and urban decisionmakers to propose more targeted interventions. The differences between this more refined metric and the regular accessibility measure are demonstrated by comparing eleven metropolitan areas across Canada (see figure 1 for an overview of the cities included in this study). As such, this study is the first to provide a comprehensive look at the state of accessibility in Canada's largest cities, and to compare these cities in terms of the equity of their transport and land use systems.

The rest of this chapter is structured as follows. Section 2 provides a literature study on accessibility metrics and the relationship between equity and accessibility. In section 3, the data and methodology used to calculate accessibility to both all jobs and low-income jobs are explained. Section 4 describes and discusses the results of the accessibility comparisons between the eleven metropolitan areas, and section 5 concludes this chapter.

FIGURE 1 - Overview of the 11 metropolitan areas included in the study

1. LITERATURE REVIEW

Accessibility, or the ease of reaching destinations, is a comprehensive metric measuring the interaction between land use and transportation (El-Geneidy & Levinson, 2006; Handy & Niemeier, 1997). The concept was first defined by Hansen (1959) (p.73) as "the potential of opportunities for interaction", and provides a measure for the variety and number of opportunities, or destinations, that can be reached from a certain point in space through the transportation network. As such, accessibility improves upon the concept of mobility by also considering potential and desirable destinations, instead of only examining an individual's ability to move.

Accessibility is generally understood to comprise four main components: land use, transportation, time, and the individual (Geurs & van Wee, 2004). Place-based accessibility metrics measure accessibility at a certain point in space, and usually only incorporate land use and transport factors due to data limitations. Person-based metrics, on the other hand, founded in space-time geography, focus on the individual, and thus also incorporate e.g. time budgets and socio-economic information (Geurs & van Wee, 2004).

Three common metrics of place-based accessibility exist. Cumulative opportunity measures of accessibility count how many destinations can be reached from a certain point in space within a certain time threshold using a certain mode, e.g. the number of grocery stores an individual can reach in 30 minutes by public transportation (Ingram, 1971; Morris et al., 1979; Wickstrom, 1971). Gravity-based accessibility measures, on the other hand, discount these destinations or opportunities by distance; the further an opportunity is, the less it contributes to accessibility (Hansen, 1959; Koenig, 1980). Such measures thus relax the assumption made by cumulative metrics that individuals stop travelling after a certain time threshold is reached, but are therefore more difficult to compute and communicate to varying audiences, reducing their chances to impact policy (Handy & Niemeier, 1997). A third set of commonly used measures are the utility-based accessibility metrics, which assign each destination with a specific utility and calculate the logsum of all destinations within a potential choice set (Handy & Niemeier, 1997). Utility-based accessibility can thus be computed as the denominator of the multinomial logit model. While such measures require extensive data collection, they can be converted into monetary units using Hicksian compensation variation, rendering them easier to communicate to urban decisionmakers (Geurs & van Wee, 2004; Niemeier, 1997).

Accessibility measures were developed with the intention of evaluating transport and land use systems, while simultaneously allowing for the ability to measure the effects of proposed plans and investment strategies (Morris et al., 1979). As such, accessibility is designed to accurately measure the benefits resulting from interacting land use and transport systems. Such benefits range from increased development potential in highly accessible locations (Ozbay et al., 2003), to land value premia generated by accessibility (Martínez & Viegas, 2009), decreased risks of social exclusion (Lucas, 2012), shorter unemployment duration for individuals experiencing high accessibility levels (Andersson et al., 2014; Korsu & Wenglenski, 2010), and lower unemployment rates among low-income households (Hu, 2017). Furthermore, accessibility has been linked with shorter commutes (Levinson, 1998) and, in areas with high accessibility via public transport, higher incidences of public transport use (A. Owen & Levinson, 2015b).

Accessibility is therefore often used to differentiate the effects of new transport plans between socio-economic groups: who stands to benefit, and who will lose (Levinson, 2014; Manaugh & El-Geneidy, 2012)? Driven by such notions of equity, transport researchers have developed a vast amount of literature discussing accessibility and equity (see, among others, Bocarejo and Oviedo (2012); Delbosc and Currie (2011); Delmelle and Casas (2012); El-Geneidy, Levinson, et al. (2016); Foth et al. (2013); Guzman et al. (2017); Lucas et al. (2016); van Wee and Geurs (2011)).

Two conflicting notions of equity exist, however. To achieve horizontal equity, accessibility should be equally divided across the entire population, regardless of individuals' socio-economic status. Vertical equity, on the other hand, would be achieved when those with the highest need experience the highest accessibility; the concept thus posits that socio-economically vulnerable populations should have higher accessibility (Karner & Niemeier, 2013).

While most scholars focus on measuring accessibility to jobs, accessibility has also been calculated to health care facilities, schools, grocery stores, and a myriad of other opportunities (Bissonnette et al., 2012; Grengs, 2015; Guagliardo, 2004; Luo & Wang, 2003; Mao & Nekorchuk, 2013). However, jobs remain the most prominent non-home destinations, and are thus particularly useful in measuring an area's attractiveness (A. Owen et al., 2016). Accessibility to jobs, besides solely giving an indication of how many jobs an individual might reach, also has the added benefit of providing a measure of nearby amenities; all services we'd like to reach, be they restaurants or the theatre, for example, employ a certain amount of people and are therefore measured within the accessibility to jobs framework. While some studies have examined and compared accessibility to jobs across different cities (A. Owen et al., 2016; Ramsey & Bell, 2014; Tomer et al., 2011), no such research has been undertaken in the Canadian context.

Despite the prominence of equity in accessibility research, there has been limited focus on specifically measuring accessibility to low-income or low-wage jobs. Such accessibility metrics provide a better representation of the state of access for vulnerable groups, as there are often non-spatial barriers to acquiring high-wage employment (Legrain et al., 2016). While most studies measuring accessibility to jobs often find that vulnerable groups experience higher accessibility levels (see for example Foth et al. (2013)), these studies usually do not specifically measure access to low-income jobs, i.e. to destinations that are more valuable for socially vulnerable populations (Legrain et al., 2016).

This study contributes to the growing body of literature on accessibility to jobs in three major ways. Firstly, we move away from the use of arbitrary time limits usually used in cumulative measures of accessibility, and instead compute the average commute (once for all commuters, and once for low-income commuters) to determine the time threshold, thereby more accurately modelling people's activity spheres. Secondly, along with calculating accessibility to all jobs, we also discern accessibility to low-income jobs, and specifically measure the latter for vulnerable groups. Finally, this paper is the first to compare such measures and the consequent equity of the transport and land use interaction across eleven major Canadian metropolitan areas, in order to provide a more holistic view on the equity of public transport provision in Canada.

2. DATA AND METHODOLOGY

To compute the accessibility to jobs metric, public transportation schedules across the eleven cities were gathered in the General Transit Feed Specification (GTFS) format from their respective transport agencies. Transit schedules were obtained for March 2017, or, when not available, for the available dates closest to this date. For large metropolitan areas with multiple providers, the schedules from all agencies were obtained with overlapping schedule dates.

Transit schedules were subsequently imported into a geographic information system through the *Add GTFS to a network dataset add-on* for ArcGIS*.* A joint network between the public transport network and the streets was then created. Travel times between census tract centroids were computed based on the joint network, through a fastest route calculation during the morning peak at 8 AM on a regular Tuesday. By creating a joint network, the algorithm would not force the fastest path to solely choose public transportation: when a route between two census tracts was faster by walking, the walking route was thus designated as the fastest. The computation for public transport travel time incorporated walking time, waiting time, and in-vehicle time based on transit schedules.

Jobs data was acquired through Statistics Canada, in the form of commute tables for each Canadian province. The tables present the number of commuters, by personal total income and mode of transport, working in each census tract; both commuters within the same census tract as those outside are counted. Abstracting unfilled positions, the total amount of individuals working in each census tract is an accurate proxy for the number of jobs in each tract.

To define the threshold for low-wage jobs, the incomes from the commuting tables were used. While these might not necessarily perfectly reflect the wage obtained from a certain job (e.g. it would overestimate a job's wage for individuals with 2 or more jobs, as their total income would be higher than any one of the two wages), the commuting tables provide a comprehensive and uniform way to define a job's wage across all Canadian provinces and metropolitan areas. To reflect local variances in the cost of living and wage distribution, the low-income threshold was determined individually for each metropolitan area as follows: the 30% lowest paying jobs in each city were designated low-income. As income was only available in brackets, the closest bracket was chosen as the threshold (e.g. if 29% of the jobs would fall within or below the $20,000-$30,000 bracket, then $30,000 would be the threshold).

Based on census tract travel times and jobs data, accessibility was computed via a cumulative accessibility metric as follows:

$$A_j = \sum_i O_i\, f(t_{ij})\ and\ f(t_{ij}) = \begin{cases} 1\ if\ t_{ij} \geq t_{threshold} \\ 0\ if\ \ t_{ij} > t_{threshold} \end{cases}$$

where A_j is the accessibility in census tract j, O_i is the number of jobs in census tract i , t_{ij} is the travel time between census tracts i and j, and $t_{threshold}$ is the average commute by public transportation in the region.

Accessibility to low-income jobs was calculated as follows:

$$ALI_j = \frac{\sum_k O_k}{\sum_k LI_k} \sum_i LI_i\, f(t_{ij})\ and\ f(t_{ij}) = \begin{cases} 1\ if\ t_{ij} \geq t_{threshold} \\ 0\ if\ \ t_{ij} > t_{threshold} \end{cases}$$

where ALI_j is the accessibility to low-income jobs in census tract j, LI_i is the number of low-income jobs in census tract i , t_{ij} is the travel time between census tracts i and j, and $t_{threshold}$ is the average commute by public transportation in the region for those travelling to low-income jobs. $\frac{\sum_k O_k}{\sum_k LI_k}$ represents the ratio of all jobs to low-income jobs in the metropolitan area (close to 10/3 per definition), and is used to scale accessibility to low-income jobs so that it is directly comparable to the accessibility to all jobs measure.

The average commute by public transportation in each metropolitan area was computed as follows. The average travel time for all public transport commuters was calculated by multiplying the number of individuals using public transport going from each census tract to each other census tract by the travel time between these census tracts, resulting in total public transport travel time in the region. This number was subsequently divided by the total number of public transport commuters to obtain average travel time in the region. For low-income commuters, a similar method was employed, but only low-income commuters were taken into account in the calculations. Thus, for each metropolitan area, the average commute for all workers and the average commute for low-income workers was computed separately. To calculate accessibility, the average commutes were rounded up or down to the nearest multiple of 5 minutes.

To discern accessibility levels by socio-economic groups, a vulnerability indicator was estimated. The indicator is composed of the following variables, based on the index for Canadian cities developed by Foth et al. (2013):

- Median household income
- Unemployment rate
- The percentage of the population that has immigrated within the last 5 years

- The percentage of households that spend more than 30% of their total income on housing rent

The final vulnerability indicator is given by the sum of the z-scores for the latter three variables, minus the z-score for the median household income. A high indicator therefore reveals high vulnerability. A census tract was subsequently designated as vulnerable if it was within the 30% census tracts with the highest indicator.

3. RESULTS AND DISCUSSION

Table 1 presents summary statistics for the 11 metropolitan areas included in this study. Note that Toronto-Hamilton refers to the entire Greater Toronto and Hamilton Area and thus includes the Toronto, Hamilton, and Oshawa census metropolitan areas as defined by Statistics Canada. The 11 included areas represent the 10 largest cities in terms of metropolitan population, plus Halifax to speak for Atlantic Canada. This subset of Canadian cities includes a wide variety of contexts, from large megalopolises such as Toronto, to smaller regional centres such as London and Halifax.

However, the size of a metropolitan area does not seem to be reflected in average commute times – in most cities this figure hovers between 45 and 60 minutes, with Winnipeg residents experiencing the shortest commutes. This might be explained by better public transport provision (such as the presence of commuter rail, subways and elevated rail) in larger cities such as Toronto, Montreal and Vancouver.

On average, it appears that low-income workers have shorter commutes. This difference is especially profound in Edmonton, where low-income workers travel 10 minutes less than average, while in London and Kitchener-Cambridge-Waterloo, low-wage commuters are forced to travel longer than average, although the difference is not large. Thus, computing accessibility at the same threshold for both low-income workers and all commuters would generally overestimate the activity spheres of vulnerable populations and thereby result in overestimates of accessibility levels. As these estimates could then feed into policy, they might result in biased recommendations that could negatively affect low-income workers.

Note that, in London and Kitchener-Cambridge-Waterloo, low-income workers travel longer on average, resulting in a higher threshold for the calculation of their accessibility. This raises questions about choice: are low-income groups in these two cities indeed more willing to travel longer, or are they travelling longer because their choices are constrained? Comparing with the 9 other cities in this study, the latter seems more plausible; this might indicate a limitation on the use of realized travel times for the calculation of accessibility. Such an approach therefore requires planners to be inimically knowledgeable about local circumstances to choose appropriate accessibility indicators.

Figures 2 and 3 present a comparison between accessibility to all jobs and accessibility to low-income jobs in Canada's three largest cities: Toronto, Montreal and Vancouver. Average accessibility levels appear to be related to a city's size and its number of jobs. Torontonians experience the largest accessibility levels on average (around 422,000 jobs in an average commute), while Vancouver inhabitants can only reach 209,000 jobs in an average commute. The average accessibility level in Montreal is 365,000 jobs.

Distinct patterns of access can be discerned from the maps: accessibility generally drops off with increasing distance from the central business district, but along rapid transit lines – commuter rail and the subway in Toronto and Montreal, or the Skytrain in Vancouver – accessibility levels, to both low-income jobs and all jobs, remain higher, reflecting the benefits conveyed by fast and frequent modes of transport. While subways seem to generate a linear pattern of high access, commuter rails only induce high access at stations, mirroring differences in stop spacing between the two heavy-rail modes. Local employment centres, on the other hand, have a minor effect on accessibility levels, as the jobs present in these areas are often dwarfed in number by those located in the central business district, or because these centres were co-located with rapid transit stops (such as at the Scarborough Centre Station in the Greater Toronto and Hamilton Area).

Interestingly, vulnerable Montreal residents are more fortunate than those in Toronto in terms of accessibility to low-income jobs: vulnerable Montrealers can access around 133,000 low-income jobs (449,000 scaled jobs), while vulnerable Torontonians can only reach 93,000 in an average commute for low-income residents (312,000 scaled jobs), even though the number of low-income jobs in Toronto is much higher.

TABLE 1 - Summary statistics for the 11 metropolitan areas

Metropolitan area	Population	Total number of jobs	Population density (pop/km^2)	Median household income (CAD)	Unemployment rate (%)	Average commute (min)	Average commute threshold (min)	Average low-income commute (min)	Average low-income commute threshold (min)	Low-income threshold (CAD)
Calgary	1,392,609	585,860	272.5	99,583	9.3	58.29	60	56.84	55	40,000
Edmonton	1,321,426	551,140	140.0	94,447	8.5	63.95	65	53.62	55	40,000
Halifax	403,390	180,860	73.4	69,522	7.3	60.14	60	54.15	55	30,000
Kitchener - Cambridge - Waterloo	523,894	227,500	480.1	77,229	6.4	45.88	45	45.90	46	30,000
London	494,069	199,090	185.6	64,743	7.3	49.23	50	51.42	50	30,000
Montreal	4,098,927	1,750,605	890.2	61,790	7.5	50.51	50	45.85	45	30,000
Ottawa - Gatineau	1,323,783	594,745	195.6	82,053	7.0	54.93	55	49.99	50	40,000
Quebec	800,296	374,680	234.8	65,359	4.6	50.26	50	46.37	45	30,000
Toronto - Hamilton†	7,055,433	2,935,930	862.4	78,437	7.6	58.37	60	52.41	50	30,000
Vancouver	2,463,431	1,004,375	854.6	72,662	5.8	49.86	50	47.41	45	30,000
Winnipeg	778,489	343,365	147	70,795	6.3	43.00	45	42.38	40	30,000

† Refers to the Greater Toronto and Hamilton Area, and includes the Toronto, Hamilton, and Oshawa census metropolitan areas

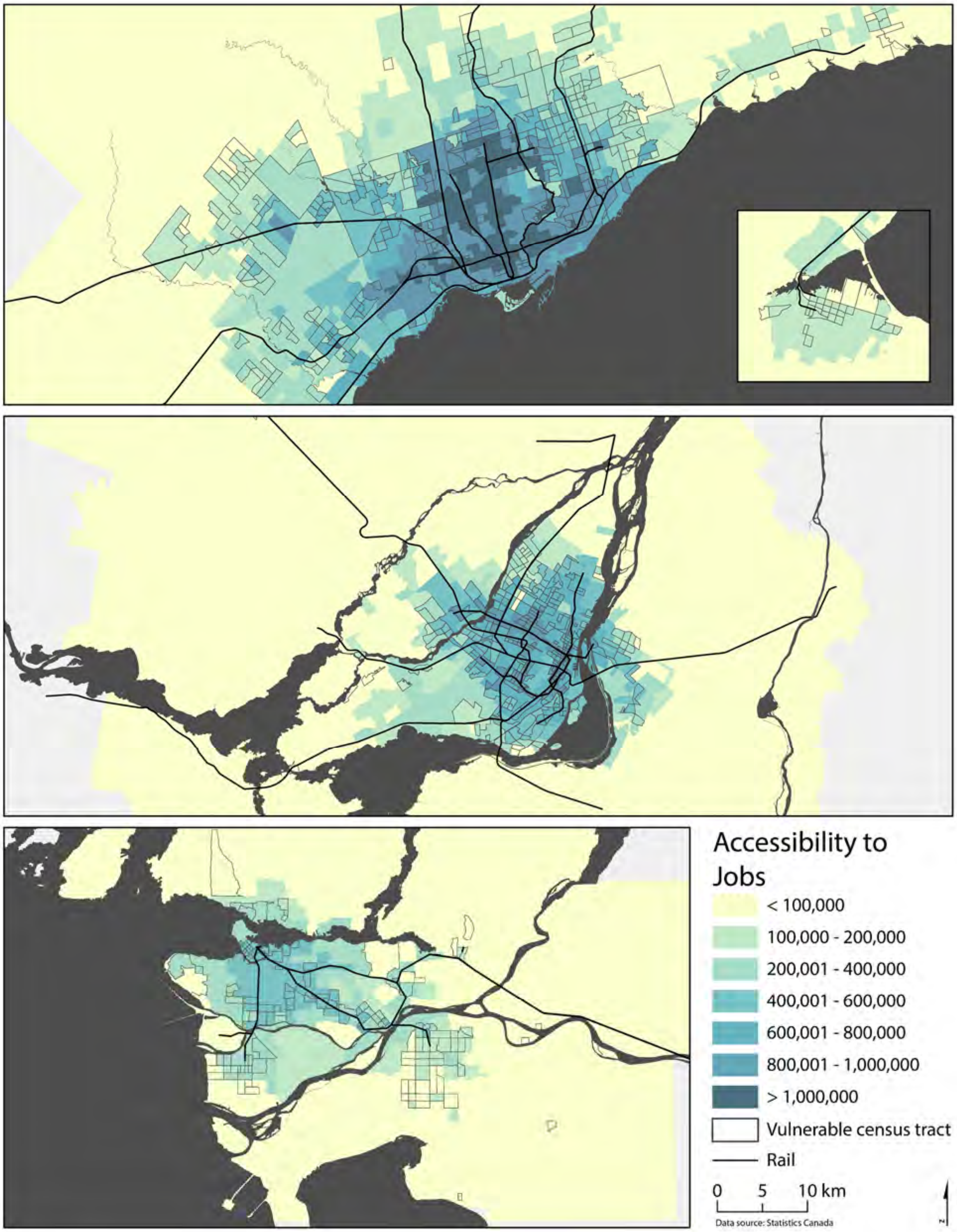

FIGURE 2 - Accessibility to all jobs in Toronto, Montreal and Vancouver

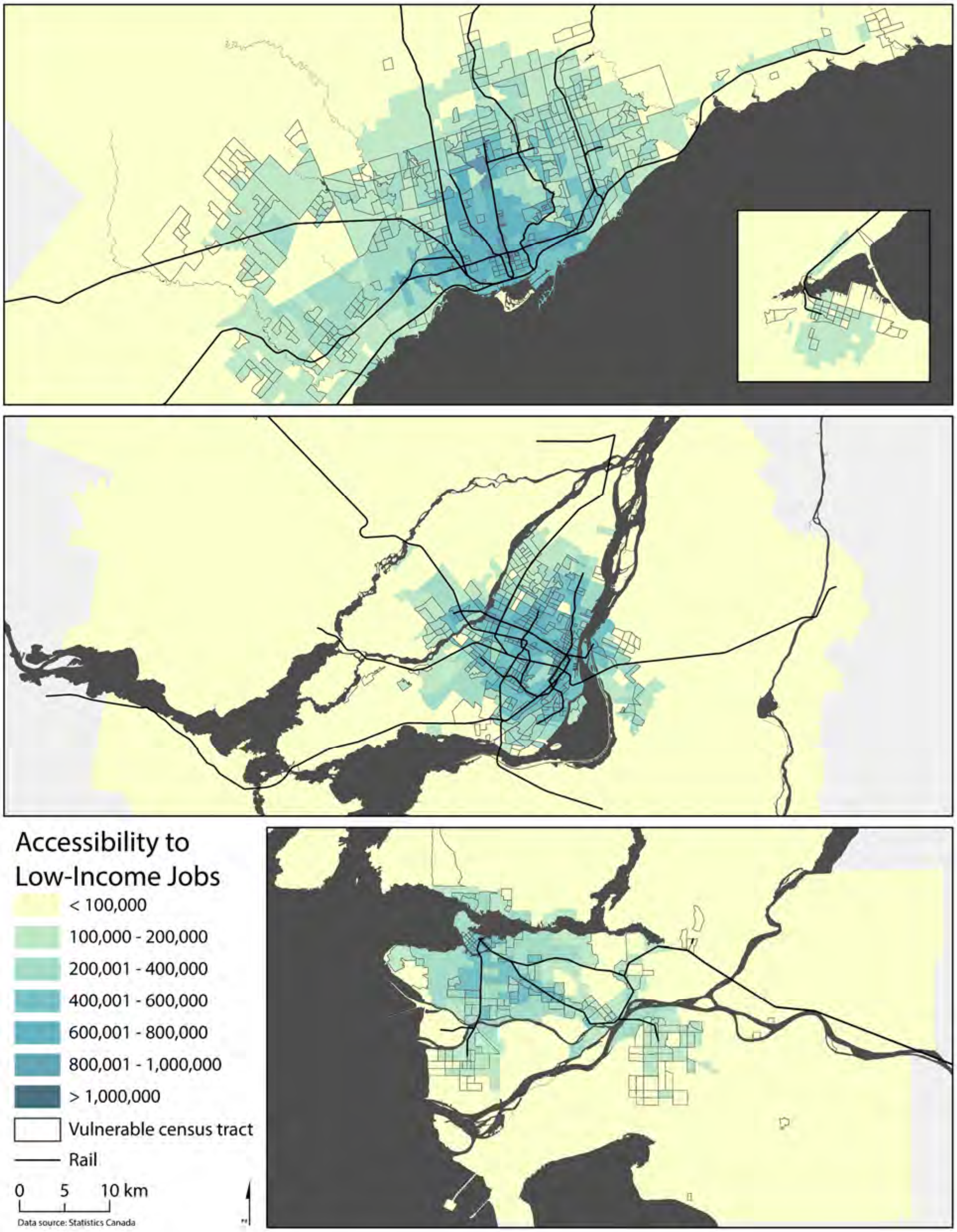

FIGURE 3 - Accessibility to low-income jobs in Toronto, Montreal and Vancouver

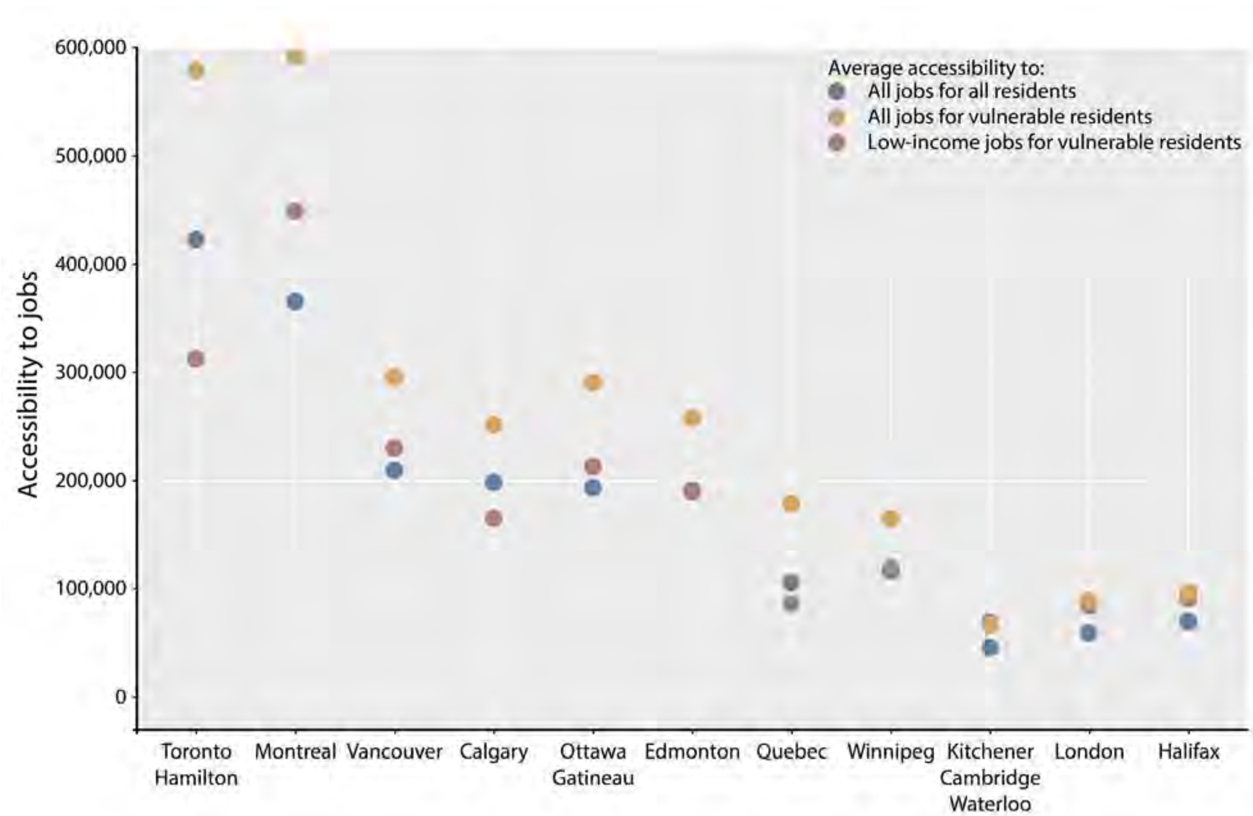

FIGURE 4 - Comparison of accessibility to all jobs and accessibility to low-income jobs

In figure 4, a comparison between average accessibility levels, to all jobs and to low-income jobs, for all cities included in this study can be seen, which again confirms the difference in access between Toronto and Montreal as noted above. The blue dots represent the commonly used accessibility to all jobs metric, while the orange dots show the average of the former metric in socially vulnerable neighbourhoods. The red dots finally represent the new metric of accessibility to low-income jobs, averaged for socially vulnerable neighbourhoods.

A city's size does not fully predict average accessibility levels; in Vancouver, for example, an average resident can only access as much opportunities as in Edmonton, Ottawa, or Calgary, which are home to around 700,000 less people and 400,000 less jobs. Similarly, inhabitants of Kitchener-Cambridge-Waterloo and London have lower accessibility than those in Halifax, even though the latter city houses 100,000 less residents. The explanation for such discrepancies are to be found in the particular allocation of land uses and the speed, frequency and coverage of the transport systems present in these cities.

Note the large differences between the accessibility to *all* jobs for vulnerable groups (orange) and accessibility to *low-income* jobs for vulnerable groups (red). These discrepancies can be explained by the difference in spatial allocation and distribution of low-income jobs versus all jobs, and by the different activity spheres and thus travel times realized by vulnerable groups. In all cities (except for Kitchener – Cambridge – Waterloo), accessibility for vulnerable individuals would have been overestimated with the commonly used all jobs metric. In Toronto, for example, policy makers only having access to an all jobs metric would conclude that vulnerable groups are better off than other residents. However, focusing only on low-income jobs that can be accessed by these individuals, it is clear that this is not the case.

In all cities, except for Toronto, Calgary, Edmonton, and Quebec, vulnerable groups still have access to a larger number of relevant job opportunities than average; vertical equity thus appears high in most Canadian metropolitan areas. Nevertheless, the variation between accessibility to all jobs and accessibility to low-income jobs for vulnerable groups (especially in Toronto and Montreal) highlights the benefits of calculating these two metrics separately.

To further illustrate the importance of distinguishing between the two accessibility metrics, we plotted accessibility against transit modal share, for both the regular accessibility measure, and the measure of accessibility to low-income jobs for vulnerable residents, see figure 5. Transit accessibility has been shown to be correlated with public transport mode share (A. Owen & Levinson, 2015b), and as such the effects of access on mode share provide a representative example demonstrating the significance of employing two separate accessibility metrics. The difference between the two accessibility levels can again be distinguished – accessibility to low-income jobs for vulnerable groups is, for most cities, higher than the regular accessibility metric.

Importantly, the effect of the accessibility metric on transit modal share differs between the two measures. While for every increase of 100,000 jobs in the regular accessibility measure, modal share increases by 4.25%, the comparable figure for the low-income accessibility metric for vulnerable groups is 6.21%. Recall that low-income accessibility was scaled by the ratio of all jobs to low-income jobs, and is therefore directly comparable to accessibility to all jobs; the contrast in effect sizes is therefore not due to a lower number of low-income jobs. Thus, vulnerable populations appear to be more sensitive to changes in accessibility to jobs they can access – had decisions been based on the regular accessibility metric, they would have considerably underestimated the effect of increasing accessibility to low-income jobs for vulnerable residents. Future research should examine the effects of accessibility to low-income jobs in further detail.

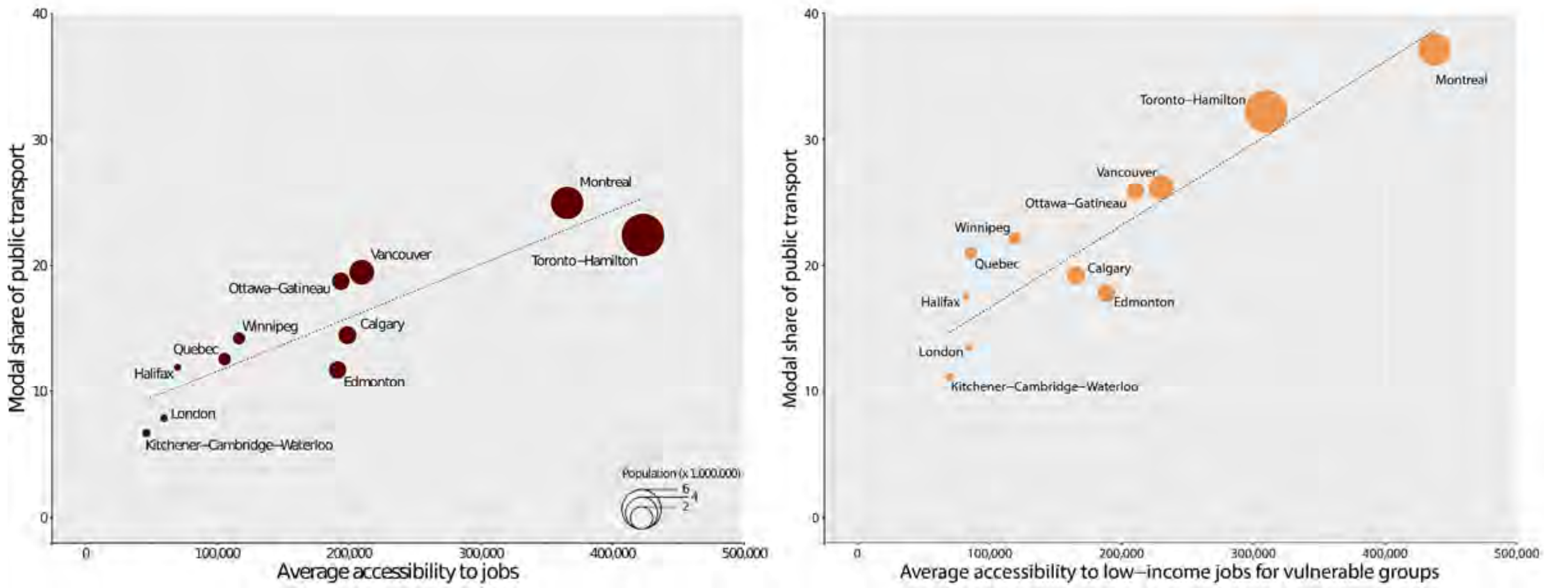

FIGURE 5 - Accessibility and public transport mode share

4. CONCLUSION

Accurate policy recommendations require the creation of adequate and robust performance indicators that can precisely measure progress. This study has therefore developed the metric of accessibility to low-income jobs for vulnerable residents, which, in contrast with commonly used measures of accessibility to all jobs, provides policy makers and urban planners with a more fine-grained tool to examine the effects of new transportation plans and projects across different socio-economic populations. In effect, this detailed accessibility measure provides a first step towards the segmentation of different groups within accessibility literature and practice – a common occurrence in studies on the different types of cyclists and public transport users (Damant-Sirois et al., 2014; Jensen, 1999; Krizek & El-Geneidy, 2007). Through such a segmentation approach, the benefits of both place-based and people-based accessibility metrics can be reconciled, namely the communicability and data requirements of place-based measures, combined with the detail common in people-based metrics.

This study has compared accessibility to all jobs by public transport, and the new metric of accessibility to low-income jobs for vulnerable groups for 11 metropolitan areas in Canada, ranging from large metropolises to smaller regional cities. On average, Toronto residents experience the highest accessibility levels. When focusing on low-income jobs, however, vulnerable groups are far better off in Montreal in terms of accessibility, even though the total number of low-income jobs is much lower than in Toronto. Overall, it appears that vulnerable individuals experience higher accessibility levels than their fellow residents in their respective cities, although this trend does not appear in Toronto, Calgary, Edmonton, and Quebec; these latter cities thus seem to lag behind their counterparts in terms of vertical equity. The discrepancies between the two metrics were further highlighted by comparing the effects of access on public transport mode share: it is clear that vulnerable residents are more sensitive to accessibility changes. Planners and urban decisionmakers, and in turn their policy recommendations, thus stand to benefit greatly from employing more detailed and segmented accessibility metrics.

CHAPTER 2: UNDERSTANDING THE RELATIONSHIP BETWEEN CHANGES IN ACCESSIBILITY TO JOBS, INCOME AND UNEMPLOYMENT IN TORONTO, CANADA[2]

In many urban areas, transport agencies are trying to provide all citizens with greater access to opportunities as a means to improve residents' well-being (Boisjoly & El-Geneidy, 2017b; Handy, 2008; Proffitt et al., 2015). Several cities particularly intend to increase access to opportunities in socially deprived areas, in order to support social inclusion and enhance the quality of life of residents in these neighbourhoods (NSW Government, 2012; San Diego Association of Governments, 2011; Transport for London, 2006). In this context, research suggests that improvements in access to opportunities by public transport can bring considerable benefits to vulnerable populations, as they are more likely to rely on this mode for accessing their destinations (Stanley & Lucas, 2008).

To quantify access to opportunities, accessibility, or the ease of reaching destinations, is increasingly being used in research and practice as a key land use and transportation performance measure. From a social equity perspective, accessibility has been used as a tool to assess the socio-spatial distribution of public transport services (Bocarejo & Oviedo, 2012; Delmelle & Casas, 2012; Golub & Martens, 2014; Kawabata & Shen, 2007), and to evaluate how changes in accessibility differ across socio-economic groups as a result of projected or new infrastructure projects (Foth et al., 2013; Manaugh & El-Geneidy, 2012; North Central Texas Council of Governments, 2016; Paez et al., 2010; Southern California Association of Governments, 2016). While a large body of literature has assessed accessibility levels for different socio-economic

[2] Co-authored with Geneviève Boisjoly and Ahmed El-Geneidy. Paper presented at the 2018 Annual TRB Meeting, Washington DC.

groups, or changes in these accessibility levels over time, little research has been conducted to assess the outcomes of such improvements in accessibility.

The goal of this study is, therefore, to assess the relationship between improvements in the levels of accessibility to jobs by public transport and the resulting socio-economic benefits, measured by changes in median household income and unemployment rate over time in the Greater Toronto and Hamilton Area, Canada. For this purpose, competitive accessibility levels to employment opportunities by transit and by car are calculated for all census tracts in 2001 and 2011. The vertical equity of accessibility by transit is then assessed for both years by comparing accessibility levels across median household income deciles. Two linear regressions are subsequently performed to examine the relationship between accessibility changes and income and unemployment at the census tract level, while controlling for the movement of residents. This study contributes to the literature on accessibility and the equity of outcome resulting from these accessibility levels, and is of relevance to planning professionals and researchers wishing to investigate the effects of accessibility improvements across neighbourhoods, especially low-income ones.

The rest of the chapter is organised as follows. Section 2 explains the concept of accessibility, examines how equity is incorporated in academic literature on this concept, and presents previous literature on accessibility, employment and income. Section 3 considers the data and methodology used to investigate the relationship between improvements in transit accessibility and changes in income and unemployment, and section 4 presents and discusses the findings. Section 5 then concludes the chapter and provides recommendations for further research.

1. EQUITY OF ACCESSIBILITY AND EQUITY OF OUTCOME

1.1 Accessibility

Accessibility was first defined by Hansen (1959) (p.73) as “the potential of opportunities for interaction”. In contrast with mobility, accessibility also considers land use factors such as the variety and number of destinations that can be reached, instead of only examining an individual's ability to move through the transportation network (Handy & Niemeier, 1997). Geurs and van Wee (2004) posit that accessibility measures should comprise four interacting components: land use, transportation, time, and the individual. Accessibility thus tries to incorporate the spatial distribution of activities, the transport system connecting these activities, the time constraints of individuals and services, and personal needs and abilities to provide a more accurate picture of the performance of transport systems.

There are several commonly used measures of accessibility, most of which take into account only the land use and transportation component, as they can be more easily computed, interpreted, and communicated, increasing their chances to impact policy (Geurs & van Wee, 2004; Handy & Niemeier, 1997). Cumulative measures of accessibility count the number of opportunities that can be reached within a set time-frame, for example the number of jobs an individual can reach within 45 minutes of travel (Wickstrom, 1971). Gravity-based accessibility measures, on the other hand, take into account that people will not stop travelling at an arbitrary time-limit, and weigh opportunities by distance; the further an opportunity is, the less it contributes to accessibility (Hansen, 1959). While more realistic, gravity-based measures require the prediction of a distance decay function, rendering them more difficult to communicate, interpret and analyze across studies.

To account for competition effects, for example among workers competing for jobs, the concept of accessibility has also been extended to include measures of competitive accessibility (Q. Shen, 1998). As cumulative and gravity-based accessibility only measure the 'supply side' of opportunities (Geurs & van Wee, 2004; Morris et al., 1979), they assume that no capacity limitations exist. Therefore, when accessibility to jobs is examined through the lens of ordinary cumulative or gravity-based accessibility measures, it is assumed that one job can be filled by an infinite number of workers. To more accurately reflect reality, a demand potential is first computed by determining how many individuals can access each opportunity. Each opportunity is then discounted by this demand potential when calculating accessibility using the cumulative or gravity-based approach in what is known as a competitive measure of accessibility (Q. Shen, 1998).

1.2 Equity of accessibility

Measures of accessibility have often been used to consider the equity of the joint benefits provided by the land use and transportation system (see for example (Delmelle & Casas, 2012; Golub & Martens, 2014; Grengs, 2015; Guzman et al., 2017)). Two different interpretations of equity in accessibility research exist, both founded in the ethical concept of egalitarianism (Foth et al., 2013; van Wee & Geurs, 2011). Horizontal equity requires that all members of society have equal access to all resources. Vertical equity, on the other hand, implies that the more vulnerable groups should be granted more resources. From this point of view, it would be more beneficial to society to increase the accessibility of unemployed young individuals than to increase the accessibility of wealthier individuals (Lucas et al., 2016). Yet another approach defines an equitable system as having a minimal gap between transit and car accessibility (Golub & Martens, 2014; Karner &

Niemeier, 2013), after which both the horizontal and vertical equity of the distribution of this gap can be measured.

Current literature mostly focuses on examining the vertical equity impacts of transportation projects. To examine this type of equity, socially vulnerable groups first need to be defined. Several studies identify socio-economic groups based solely on income (for example (Fan et al., 2012; Guzman et al., 2017)), whereas other studies also examine race, poverty status, minorities, and housing characteristics (Delmelle & Casas, 2012; Golub & Martens, 2014; Grengs, 2015), or create a social indicator combining several of these measures (Foth et al., 2013). The vertical equity of accessibility can then be investigated by comparing accessibility levels across different populations.

A distinction is often made between equity of opportunity and equity of outcome (Delbosc & Currie, 2011; Litman, 2002; van Wee & Geurs, 2011). Studies discussing the horizontal and vertical equity of accessibility address equity of opportunity, but refrain from making judgements on the outcome of the process. This paper attempts to connect the two concepts by considering the link between equity of opportunity, measured by accessibility, and equity of outcome, measured by changes in unemployment and income over time.

1.3 Accessibility, unemployment and income

To determine the outcomes and subsequent benefits resulting from accessibility and accessibility changes, previous studies have focused on examining the relationship between accessibility to jobs and socio-economic status, mostly concentrating on unemployment duration. Korsu and Wenglenski (2010), using micro-data, demonstrate that low accessibility to jobs is related to high unemployment in Paris, and find that workers living in areas with very low accessibility have a 1.7% higher probability of being unemployed for longer than one year compared to workers living in neighbourhoods with medium accessibility. To this end, the authors use a measure of cumulative accessibility, by public transport or car depending on car ownership, specifically considering the employment opportunities of the same socio-professional status as the individuals in question. Andersson et al. (2014) investigate low-income workers who were subject to mass layoffs in several US cities, and find that high accessibility to jobs is associated with a reduction in the time spent looking for work. A competitive measure of accessibility to low-income jobs is used for this purpose, taking into account the probability of using car or public transport, and explicitly considering competing job searchers to account for labour market tightness. Tyndall (2015) notes that after the closure of the R train in Brooklyn due to hurricane Sandy, unemployment rates along the line increased considerably, especially for those without a private vehicle, demonstrating that substantial changes in the public transport system affect unemployment. This study did not, however, examine the accessibility impacts of this endogenous shock to the transport system. Blumenberg and Pierce (2014) find that living close to a bus stop highly increases the chances of maintaining consistent employment, while having access to a private automobile has also been shown to be related to increased employment (Blumenberg & Pierce, 2017). Larson (2017) examines the relationship between access to jobs by public transport (broadly defined as the observed transit modal share) and economic opportunity over four decades in four US cities, and concludes that there is a positive relation between transit access and economic opportunity in predominantly white neighbourhoods in Orlando and Minneapolis, while a similar relationship is present in non-white areas in Birmingham.

This emerging body of literature suggests that accessibility to jobs is a potential determinant of unemployment duration. However, little is known about the relationship between unemployment rates and accessibility over time at a more aggregate, metropolitan scale; the literature presented above has not examined how accessibility changes impact longer term unemployment duration and more aggregated unemployment rates. Furthermore, no study has, to our knowledge, examined changes in accessibility and median household income over time. To provide a more holistic view on the relationship between accessibility changes and consequent changes in socio-economic status at an aggregate level, this study attempts to investigate the change in both the unemployment rate and median household income over a ten-year period. This paper therefore contributes to the literature by presenting a long-term study associating a robust accessibility measure with equity of outcome.

2. DATA AND METHODOLOGY

2.1 Study context

The Greater Toronto and Hamilton Area, the most populous metropolitan region in Canada, housing 5.6 million residents in 2001 and 6.6 million inhabitants in 2011, was chosen to examine the relationship between transit accessibility improvements and changes in income and unemployment. The region is well connected by public transport, and is home to a subway, commuter train system and bus network (Figure 6). While the subway only serves the City of Toronto, the bus and train network extend across the entire region. During the ten-year study period, several infrastructure projects altered the public transport network in the area. In 2002, a new subway line, the Sheppard line (the line shown in green in figure 6), was opened, serving five new stations in the north of the City of Toronto. Additionally, several new train stations were constructed and new express bus services were introduced. At the same time, transit mode share increased from 20% in 2001 to 21% in 2011.

2.2 Data

Three different data sources were used for the analysis. Census and employment data for 2001 and 2011 were obtained from Statistics Canada. This data was enriched by a cumulative accessibility measure for a 45-minute trip by transit in 2011 at the census tract level, derived from GTFS data. The third data source, Metrolinx, provided travel time from 2001 at the traffic analysis zone (TAZ) level, calculated through the EMME travel demand modelling software, for both public transportation and automobile. Additionally, car travel time from 2011 during the AM peak was also supplied by Metrolinx.

A competitive measure of accessibility for 2001 at the TAZ level was first calculated using 2001 travel times and employment. Competitive accessibility is given by:

$$A_m^i = \sum_j \frac{O_j f(t_{ij}^m)}{D_j^m}, \text{ where } D_j^m = \sum_j LF_j\, f(t_{ij}^m)$$

A_m^i reflects the accessibility at point i for transportation mode m, O_j is the number of opportunities at location j, and $f(t_{ij}^m)$ is 1 when the travel time between locations i and j (t_{ij}^m) is smaller than the set-time limit, and 0 otherwise. D_j^m represents the demand for the opportunities at location j, and is given by the total labour force (LF_j) that can access those opportunities within the set time-limit. To ensure consistency with available data from 2011, and to allow for comparisons, the accessibility measure was calculated for a 45-minute trip limit for public transport, and a 30-minute limit for car, and then projected into 2011 census tract boundaries through a nearest neighbour interpolation. These time limits reflect the average commute times in Toronto for both modes (49 and 29 minutes respectively (Statistics Canada, 2010)), in order to capture the opportunities an individual can access in an average trip, while accounting for competition from other residents trying to reach the same opportunities.

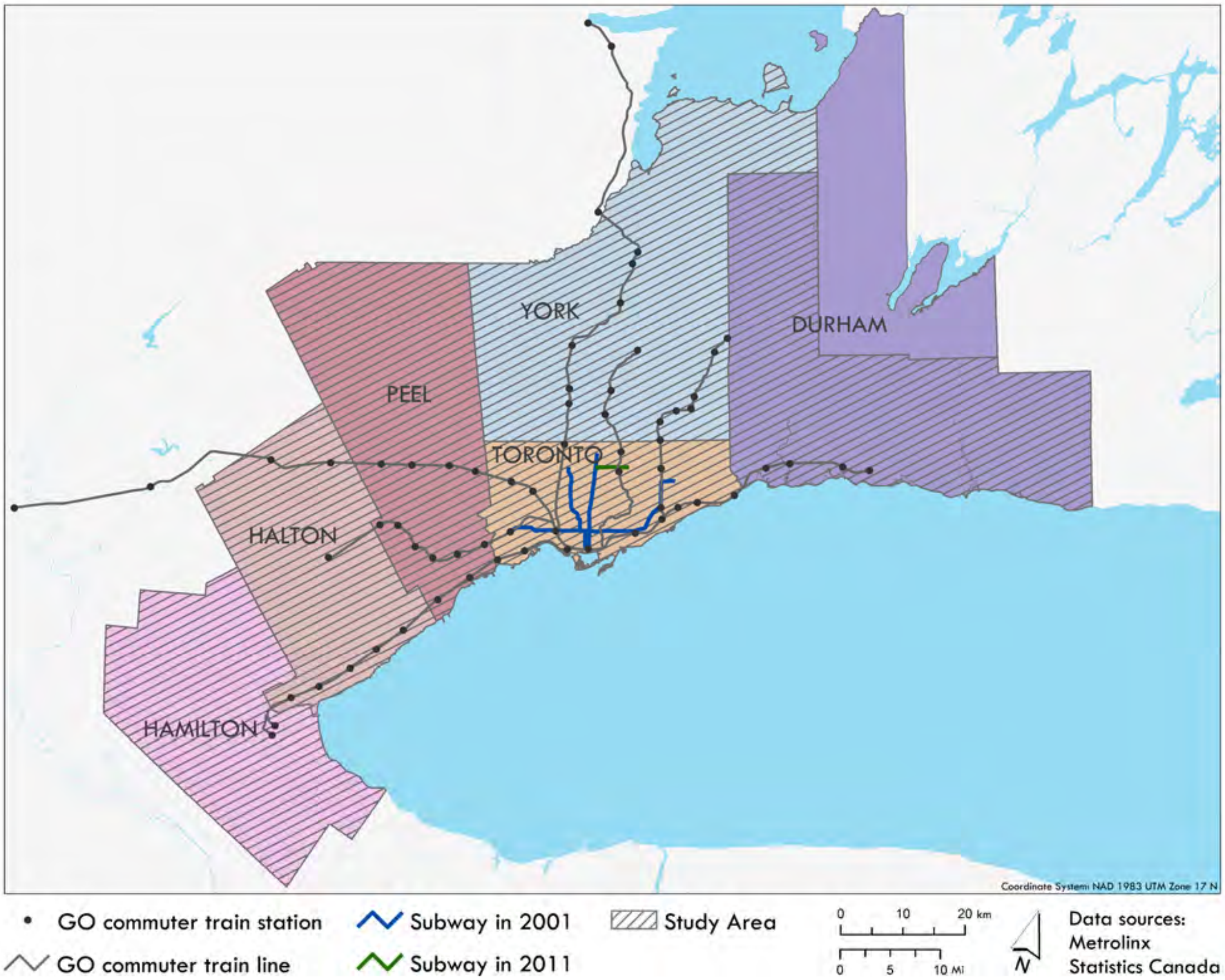

FIGURE 6 - Context map

2.3 Methodology

To investigate the relationship between improvements in transit accessibility and changes in the unemployment rate and median household income, two linear regression models are employed. The first model predicts median household income in 2011, based on median household income in 2001 and changes in accessibility by car and transit between the two years. The second model is specified in a similar manner: the unemployment rate in 2011 is related to the unemployment rate in 2001 and changes in accessibility levels.

As changes in income, especially for low income census tracts, could be related to gentrification, i.e., the upgrading of the socio-economic status of a neighbourhood through local migration (Lyons, 1996), several additional variables are added to the model. Literature on the relation between transit and gentrification usually investigates land and housing values, changes in income, race, car ownership, the number of professionals, and educational attainment to identify gentrifying areas (Grube-Cavers & Patterson, 2015; Kahn, 2007; Pollack et al., 2011). A neighbourhood is said to be gentrifying if these variables change faster than the average in the metropolitan area. Such an approach, however, does not account for the movement of people. Some of the changes noted by the literature could, instead of being linked to gentrification, have resulted from an improvement in the conditions of the individuals living in a certain neighbourhood, without the presence of outside forces pushing these residents out; increases in income do not always imply that people were pushed out and wealthier individuals moved in (Freeman, 2005). Also incorporating the percentage of people moving mitigates these disadvantages and acknowledges that in-movers are the driving force behind gentrification (Freeman, 2005). Consequently, the change in the percentage of residents with a bachelor's degree or higher, and the percentage of residents that have moved between 2006 and 2011 are included in the regression model to control for the effects of gentrification, and, more broadly, migration. The summary statistics of the variables used in the two models are shown in table 2.

TABLE 2 - Summary statistics

Variable	Mean	Standard dev.
Median Household Income in 2011 ($1,000)	75.664	26.536
Median Household Income in 2001 ($1,000)	64.534	21.558
Unemployment rate in 2011 (%)	8.7173	3.1598
Unemployment rate in 2001 (%)	5.7868	2.4814
Change in competitive accessibility by transit (jobs/worker)	-0.0897	1.1893
Change in competitive accessibility by car (jobs/worker)	0.2422	0.2917
Change in percentage of residents with a bachelor's degree or higher (%)	4.3710	4.9699
Percentage of residents that have moved between 2006 and 2011 (%)	35.131	11.480

3. RESULTS AND DISCUSSION

Figure 7 shows the spatial distribution of median household income and the unemployment rate in the GTHA in 2001 and 2011. In the top two maps, the lightest colour represents the census tracts with the lowest income, whereas the darkest color represents the least vulnerable neighbourhoods. In both years, the low-income census tracts are centred in a ring around downtown Toronto, although a suburbanization of low income areas has occurred; the neighbourhoods to the north and east of the City of Toronto have become more vulnerable in 2011. The outer suburbs, as well as the CBD of Toronto, house higher income populations in both years. In the bottom map, the lowest unemployment rate is presented in the lightest color, while the highest unemployment rate is shown in the darkest color. The financial crisis of 2007-2008 radically changed the pattern of unemployment across the region: the unemployment rate skyrocketed between 2001 and 2011 in almost every census tract, especially in the outer suburbs.

The spatial distribution of competitive accessibility by public transport and car in both 2001 and 2011 are shown in figure 8. Transit accessibility was calculated for a maximum travel time of 45 minutes, whereas car accessibility was computed for a 30-minute trip. The two modes display profoundly different spatial patterns, due to significant directionality present in the public transport system. During the morning peak, the GO train network focuses on bringing residents into the Toronto CBD, while the service in the opposite direction is close to non-existent. Suburban job centres are therefore protected from competition by transit: only local residents can access these employment opportunities, resulting in high competitive accessibility levels. Competitive accessibility by transit is thus mainly determined by competition effects. In contrast, accessibility by car is mostly influenced by the presence of job opportunities, as directionality is less present in the highway and street networks. Car accessibility is thus highest in downtown Toronto, where the largest amount of job opportunities is present. Between 2001 and 2011, accessibility by private automobile rose substantially in Toronto and in the western parts of the region, whereas a small decrease was observed in the eastern census tracts. At the same time, competitive accessibility by transit increased in a few clusters of suburban job centres, and decreased in the rest of the Greater Toronto and Hamilton Area.

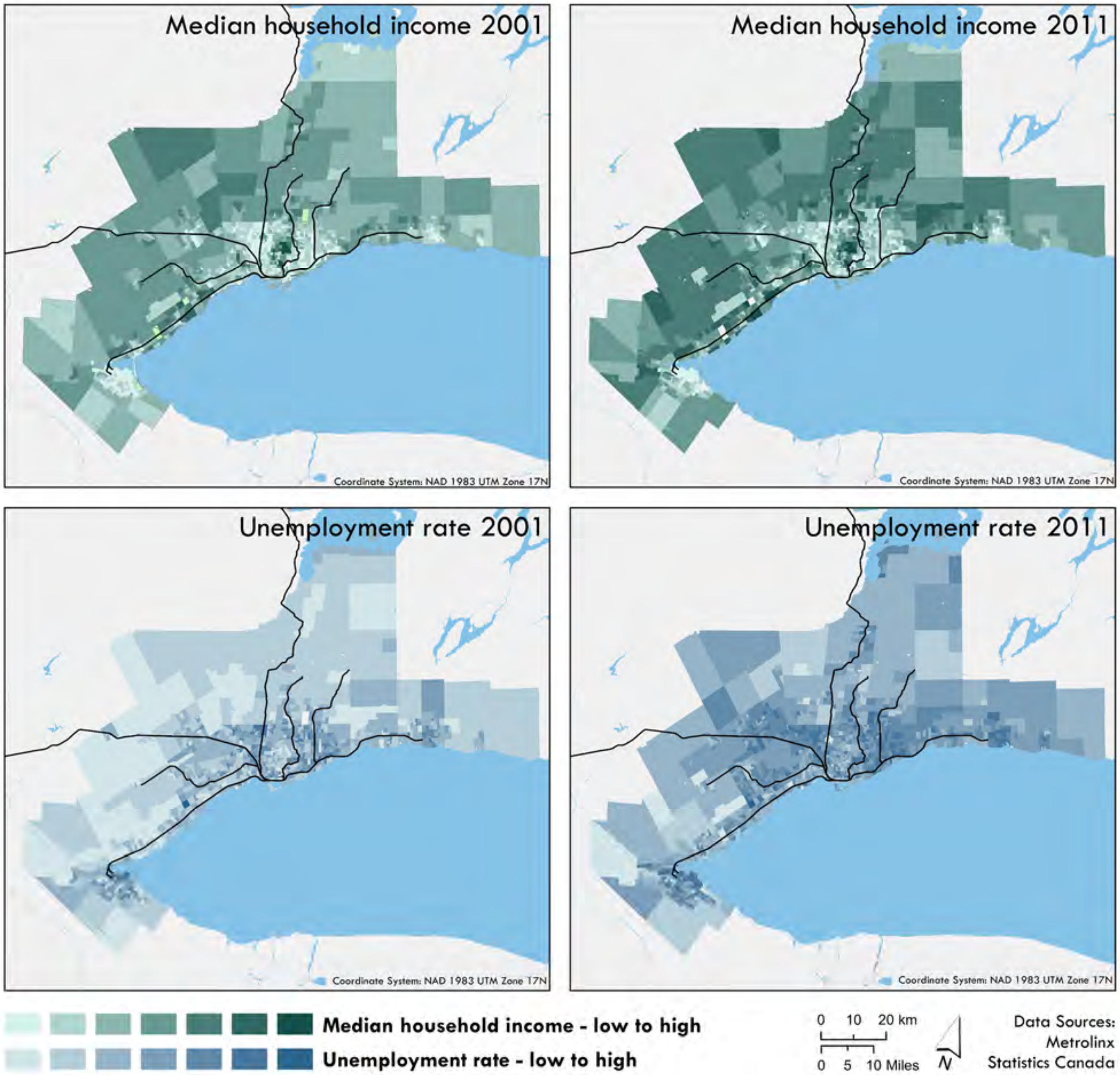

FIGURE 7 - Median household income and unemployment rate in the GTHA in 2001 and 2011

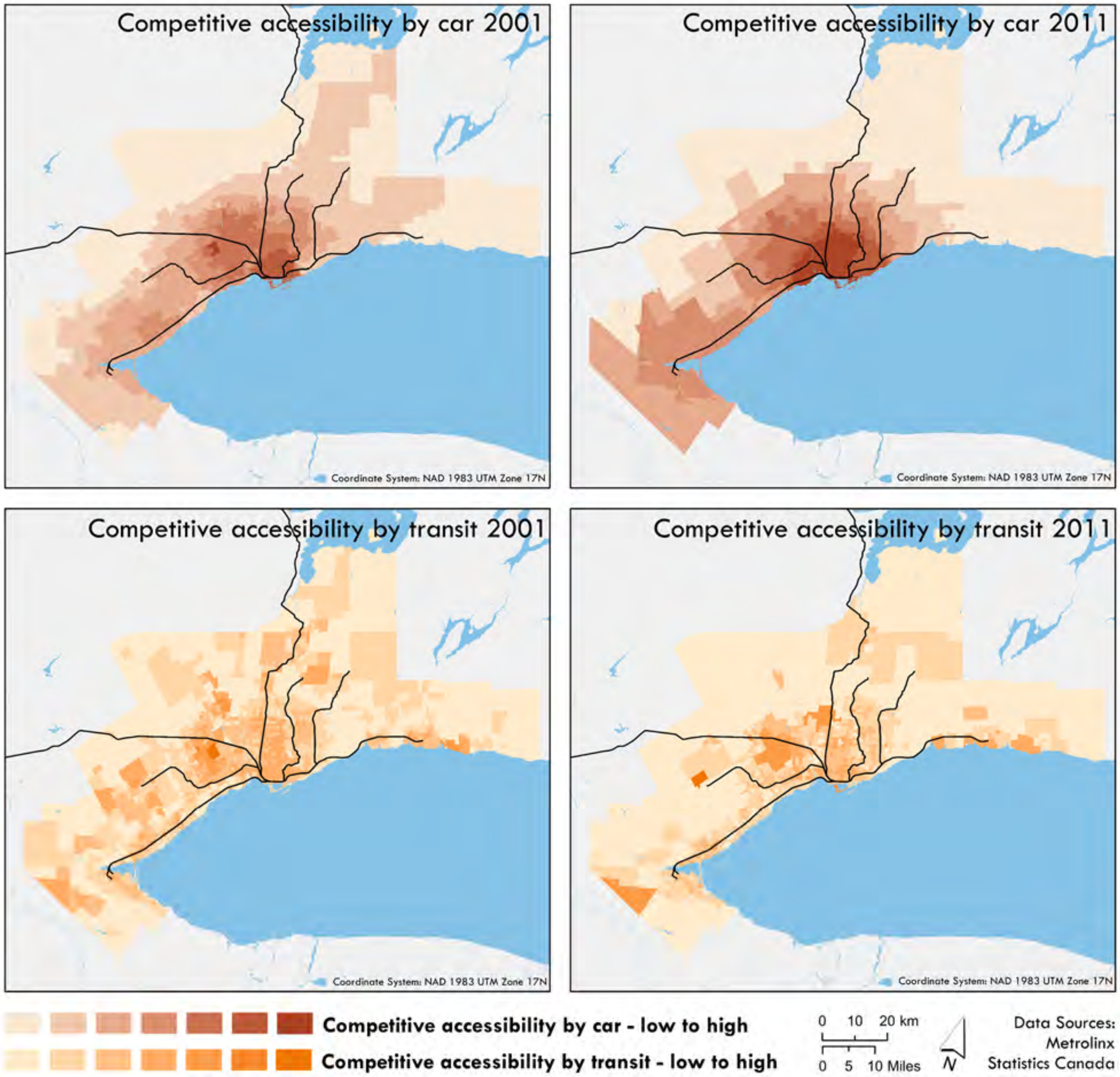

FIGURE 8 - Transit accessibility in the GTHA in 2001 and 2011

3.1 Vertical equity

Figure 9 presents transit accessibility standardized values (z-scores) by income decile. In 2001, the four deciles with the lowest income in the region experience considerably higher competitive accessibility levels by transit than all other groups, highlighting that accessibility is vertically equitable in the GTHA, which is consistent with the findings of Foth et al. (2013) for the Greater Toronto and Hamilton Area. Competitive accessibility of the four groups with the lowest income decreased between the two years, however, although they continue to have a considerably higher accessibility than the other income deciles. The investments in commuter trains, connecting wealthier neighbourhoods to downtown Toronto, have therefore succeeded in increasing accessibility to employment for high income census tracts. This suggests that, while the vertical equity of the transportation and land use system is still high in the GTHA, there is a trend towards decreasing vertical equity and increasing horizontal equity. Note that, as socially vulnerable groups have lower car ownership (Potoglou & Kanaroglou, 2008), this decrease in accessibility can result in substantial negative consequences for the region's most vulnerable populations. To quantify the effects of these accessibility changes on neighbourhood socio-economic status, results of the linear regression models are presented in the next section.

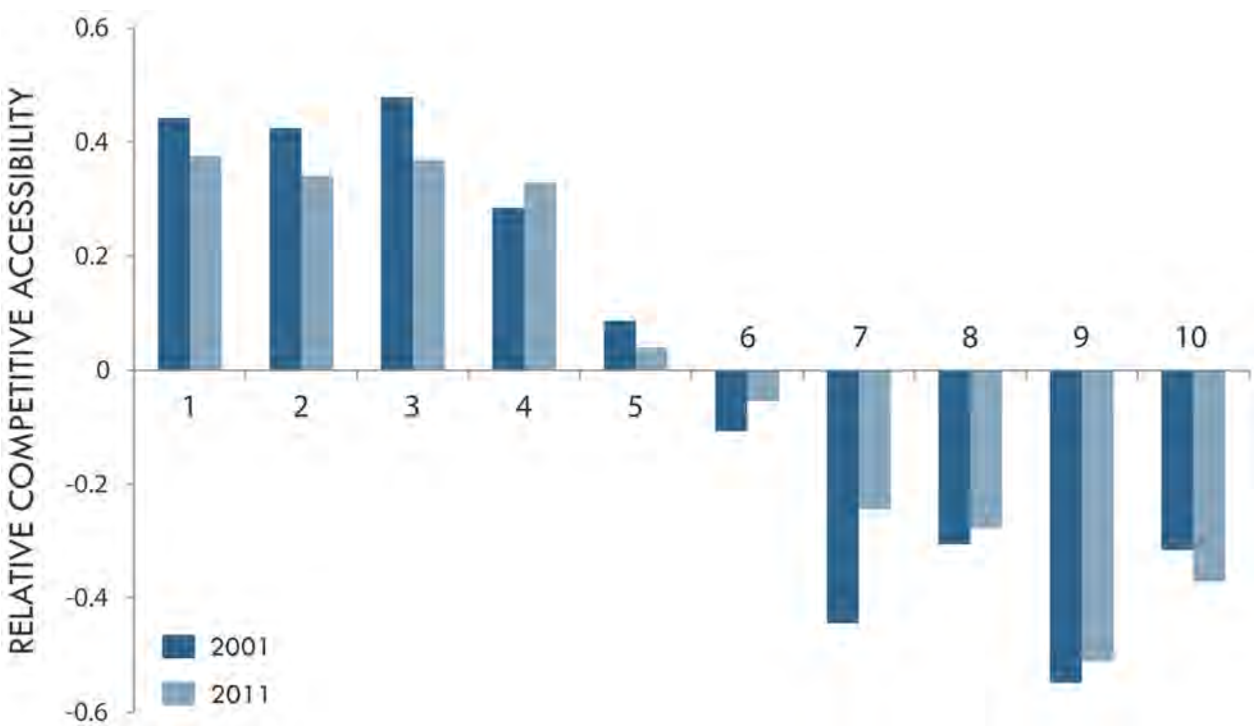

FIGURE 9 - Relative competitive accessibility by transit, by income decile in the GTHA

3.2 Linear regression models

Table 3 shows the results of the two linear regression models, with both models showing similar patterns. Only the variables that are statistically significant will be described here. The model predicting median household income in 2011 demonstrates that higher median household income in 2001 is associated with higher median household income in 2011, while the coefficient of 1.12 for this variable suggests that overall income levels rose by 12% during the study period, while controlling for all other variables present in the model. Changes in competitive accessibility by transit, and the interaction term between this variable and median household income in 2001, are significantly related to income in 2011. For example, a census tract with a median household income of $40,000 in 2001 is predicted to have an extra increase in income of (7.67 – 0.099*40) = 3.71 ($3,710) in 2011 per extra unit in competitive accessibility (Table 3). A one unit increase in competitive accessibility occurs when a person can access an extra job that is not accessible to all other residents in the region. The effect of competitive accessibility reverses when income in 2001 is higher than $77,475. As higher income populations are more likely to move to less dense areas in search for open space, they tend to migrate to areas without public transport access. As a result, median income decreases in areas where these wealthy groups move out. Increases in competitive accessibility by car are also statistically significant and associated with higher incomes in 2011: a one unit increase in car accessibility is predicted to increase income by $3,370. An interaction term between car accessibility and baseline household income in 2001 was also analyzed, but was not significant, indicating that the effect of accessibility by car is income-independent.

The remaining statistically significant coefficients highlight that increases in the percentage of residents with a bachelor's degree or higher, and stable neighbourhoods (without many people moving) are related to higher median household incomes in 2011. The coefficients for accessibility changes by both car and public transport highlight that changing equity of opportunity, measured by accessibility, is associated with a changing equity of outcome, measured by income.

The second model indicates that higher unemployment rates in 2001 are associated with higher unemployment rates in 2011, suggesting that census tracts with high unemployment rates in 2001 still have higher unemployment in 2011. An extra accessible job by transit that cannot be reached by any other individual (a one unit increase in transit accessibility) is related to a 2.5 percentage point decrease in unemployment rate for census tracts with a median household income of $0. If median household income in 2001 increases, the effects of changes in transit accessibility lessen and reverse at a median household income of $78,052. In contrast, the change in car accessibility has a uniform effect across income: one extra accessible job by car that cannot be reached by others is linked to a decrease of 0.54 percentage points in unemployment rate. As with the model predicting income, increases in the percentage of residents with a bachelor's degree or higher are significantly associated with lower increases in the unemployment rate. These results are consistent with the findings presented by Tyndall (2015), who found that a substantial change in the provision of public transport (and thus a considerable change in access by transit) was associated with changing unemployment. This suggests that the conclusions by Korsu and Wenglenski (2010) and Andersson et al. (2014) can be extended from unemployment duration at the individual level to aggregated unemployment rates at the neighbourhood scale.

Table 4 presents predicted values for median household income and the unemployment rate in 2011 for all income deciles in 2001. The values are predicted for a constant transit accessibility, and for a transit accessibility that increased by one unit during the study period. Median household income in 2011 is greater for all deciles except the two wealthiest groups if accessibility by public transport increased instead of remaining constant. The premium generated by transit accessibility ranges from $3,812 for the lowest income decile to -$13,744 for the highest income decile. A similar pattern is present in the predicted unemployment rates: the predicted effect of a unit increase in competitive accessibility by transit is -1.28 percentage points for the poorest census tracts, and 4.52 percentage points for the wealthiest decile. Based on these predictions, we can infer that the decreasing vertical equity of transit accessibility (as shown in figure 9) is associated with a widening of the income gap in the GTHA.

TABLE 3 - Regression results for census tract median household income and unemployment rate in 2011 in the Greater Toronto and Hamilton area

Variable	Income				Unemployment rate			
	Coefficient	Sig.	Confidence interval†		Coefficient	Sig.	Confidence interval†	
Constant	5.11	***	2.071	8.15	4.7788	***	4.2652	5.2925
Median household income in 2001	1.121	***	1.093	1.149	-	-	-	-
Unemployment rate in 2001	-	-	-	-	0.6986	***	0.6362	0.761
Change in accessibility by transit	7.67	*	1.276	14.065	-2.5523	**	-4.2517	-0.8529
Change in accessibility by transit • Median household income in 2001	-0.099	*	-0.181	-0.016	0.0327	*	0.0108	0.0546
Change in accessibility by car	3.37	***	1.49	5.249	-0.5402	**	-1.0368	-0.0436
Change in percentage of residents with a bachelor's degree or higher	0.664	***	0.554	0.775	-0.093	***	-0.1232	-0.0627
Percentage of residents that have moved between 2006 and 2011	-0.154	***	-0.206	-0.103	0.0116		-0.0020	0.0252
Adjusted R^2	0.8695				0.352			

Dependent Variables: Median household income in 2011 ($1,000), Unemployment rate in 2011 (%)
* 95% significance level | ** 99% significance level | *** 99.9% significance level
† 95% confidence interval

TABLE 4 - Predicted 2011 income and unemployment rates for each income decile in 2001

			Change in transit accessibility = 0		Change in transit accessibility = 1	
Income decile	**Income 2001**	**Unemployment rate 2001**	**Predicted income 2011**	**Predicted unemployment rate 2011**	**Predicted income 2011**	**Predicted unemployment rate 2011**
1	38,967	9.7260	47,100	11.4435	50,913	10.1655
2	45,353	7.5418	54,260	9.9177	57,440	8.8484
3	50,835	6.5180	60,404	9.2024	63,042	8.3124
4	57,487	5.8651	67,860	8.7463	69,839	8.0738
5	63,125	5.6117	74,182	8.5693	75,603	8.0812
6	70,204	5.0530	82,117	8.1790	82,837	7.9223
7	75,605	4.6826	88,172	7.9202	88,357	7.8402
8	81,954	4.6638	95,289	7.9071	94,846	8.0347
9	89,749	4.1651	104,026	7.5587	102,811	7.9411
10	216,308	4.0577	245,900	7.4837	232,155	12.0046

4. CONCLUSION

Accessibility to jobs by public transport is a key factor explaining the quality of life of individuals. Results show that accessibility to jobs by public transport is relatively vertically equitable in the Greater Toronto and Hamilton Area, although vertical equity decreased between 2001 and 2011. The census tracts with the lowest income boast the highest accessibility to jobs thanks to their proximity to downtown Toronto and the public transport network, while wealthier groups experience lower accessibility levels.

This study suggests that, for low and medium income census tracts, increases in transit accessibility are related to higher increases in income. For wealthier census tracts, increases in transit accessibility are associated with decreases in income, potentially due to the migration of high-income populations to less dense neighbourhoods, away from transit. The change in accessibility by car, on the other hand, has a uniform effect across income deciles and is associated with larger income increases. The equity of accessibility to employment opportunities thus plays a key role in determining resulting equity of outcome, stressing the need for methods that can incorporate equity considerations into the evaluation of new transportation projects.

It is important to note that the findings from this study are not conclusive, nor can they determine a causal relationship; more analysis is needed in multiple cities across the globe to further investigate the relationship between accessibility improvements and changes in income and unemployment. While multiple variables related to migration were examined, this study does not fully capture the impacts of population movement between 2001 and 2011. The uncovered relationship could therefore potentially be explained by transit accessibility attracting medium income populations, resulting in increases in income for low income areas, and decreases in income for the wealthiest neighbourhoods. This highlights the need for further research in order to disentangle the complex socio-spatial relationships uncovered in this study. Ideally, future research should employ micro-data to track individuals over time, and use surveys and interviews to shed more light on individual changes in accessibility and socio-economic status.

Future studies should also include the cost of transportation in their analysis and normalize the fares according to income. This would lower the accessibility of the entire population (El-Geneidy, Levinson, et al., 2016), and could reduce accessibility for socially vulnerable groups compared to wealthier groups.

Different types of jobs were not distinguished in the present study, although people cannot access all the different jobs that exist within a city; an individual without a high school diploma will not be able to access the high-wage service-sector jobs that cities offer, regardless of the transport and land use system. Future studies should therefore differentiate low, medium, and high income jobs when comparing accessibility across different groups and different years. The analysis should also take into account the time when different jobs start and incorporate the time aspect in the calculation of accessibility by public transport.

Nevertheless, the results of this study demonstrate a clear association between improvements in accessibility by transit and positive outcomes (measured by changes in income and unemployment) for neighbourhoods with low and medium income. The relationship uncovered in this study establishes new directions for future research in order to explore the equity of outcome resulting from changing accessibility levels.

ACKNOWLEDGEMENTS

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CHAPTER 3: ACCESSIBILITY-ORIENTED DEVELOPMENT[3]

Local authorities worldwide continue to pursue transit-oriented development (TOD) strategies in order to increase transit ridership, curb traffic congestion, and rejuvenate urban neighbourhoods (Cervero et al., 2002; Curtis et al., 2009; Papa & Bertolini, 2015; Ratner & Goetz, 2013). For years, TOD has garnered attention by scholars and transport professionals alike (Calthorpe, 1993; City of Denver, 2014; Gilat & Sussman, 2003). Neighbourhoods are often defined as TODs when they are situated close to transit, allow for higher density development, and possess diversified land uses (Cervero et al., 2004; Kamruzzaman et al., 2015). TOD therefore not only involves the construction of public transport infrastructure and provision of service, but also requires the integration of transport and land use (Bertolini et al., 2012; Jacobson & Forsyth, 2008); in this way, TOD intends to achieve a holistic way of compact urban development, enabled by supporting public sector policies such as zoning and tax incentives. As TODs usually also encompass increased attention to urban design, livable spaces and walkability, the demand for housing in TOD areas results in increased premiums for homes located in TODs (Duncan, 2011; Mathur & Ferrell, 2013; Renne, 2009). Residents in these areas have also been found to rely more on transit and active modes of transport, seemingly fulfilling the promises of TOD (Chatman, 2006; Kamruzzaman et al., 2015), although the relationship between TOD and transit use has been found to differ between trip motives (Langlois et al., 2015), and not the ‘T’ in TOD, but rather limited parking availability and higher density may be causing the observed decrease in car use (Chatman, 2013).

Areas planned as TOD do not always function as foreseen; in many cities, development on planned sites has been close to non-existent. One potential reason is that the connection between the (planned) transit investment and land use at both the local and broader spatial scale are often

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overlooked. At the local scale, transit-adjacent developments (TADs) may fail to take advantage of their proximity to transit and bring almost none of the benefits normally associated with TODs (Renne, 2009). The often physical nature of the definition of TODs ('density near transit') contributes to this problem (Belzer & Autler, 2002).

However, it is at the regional scale that the TOD concept tends to break down more often. TOD is an inherently local planning tool, and does, at its core, not consider regional land use patterns. While regional approaches to TOD planning have been proposed (see e.g. P. Newman (2009); Staricco and Vitale Brovarone (2018)), they are not sufficient to combat this issue and their use is far from widespread. The TOD concept, even in its regional variant, only considers access *to* transit, but not the accessibility that is provided *by* transit (i.e., what destinations does the transit service allow me to access?) (Belzer & Autler, 2002; Guthrie & Fan, 2016; Renne, 2009). As travel patterns are mostly determined by the region-wide levels of accessibility provided *by* transport systems, the use of TOD, as such, is insufficient to increase transit usage (Boarnet, 2011; Chatman, 2013) and to attract urban development. We contend that these issues can be alleviated by introducing the concept of accessibility-oriented development (AOD).

AOD will help planners to explicitly consider not just access *to* transit, but also the accessibility provided *by* transit. Accessibility, or the ease of reaching destinations, is an easy-to-use measure that can help unravel the intricacies involved in combined land use and transport planning in the minds of planning professionals and urban decision makers (Boisjoly & El-Geneidy, 2017a). *Access to destinations* is usually operationalized as the number of destinations that can be reached from a certain point in space. As such, accessibility recognizes the inherent connection between transport and regional land uses (in the form of destinations) and can be used to overcome the local focus of TODs.

We define accessibility-oriented development as a strategy that balances accessibility between employment opportunities and workers to foster an environment conducive to urban development. AOD occurs both naturally through the market and with direction from planners. The AOD concept invites planners to leverage access to steer, slow down, or speed up the phenomena that naturally follow from accessibility changes, namely changing commute times and economic development. AOD areas are therefore neighbourhoods or sites where planners are using the various tools at their disposal to control accessibility levels in order to attract a particular mix of residential, commercial or industrial development. We hypothesize that transport investments made on the principles of AOD planning will naturally result in development occurring in the targeted neighbourhoods, and, through lower commute times, a better quality of life for residents. This study aims to test the hypotheses underlying the accessibility-oriented development concept.

The rest of this chapter is organised as follows. Section 2 describes the concept of accessibility and links it with economic development. Section 3 defines AOD more thoroughly and assesses the validity of using AOD, by testing the two underlying hypotheses in a case study of the Greater Toronto and Hamilton Area, Canada, using access to jobs and workers in 2001 and 2011. In Section 4 the results of the regression models testing AOD are discussed. Section 5 then concludes the chapter and provides policy recommendations for the implementation of AOD.

1. LITERATURE

1.1 Accessibility

Accessibility is a comprehensive measure of the land use and transport interaction in a region and illustrates the ease of reaching destinations (Geurs & van Wee, 2004; Handy & Niemeier, 1997). Accessibility was first defined by Hansen (1959), who used the measure to develop a residential land use model, under the assumption that accessibility was a main driver of residential development. This paper builds on this seminal work by testing the relationship between accessibility and development across different modes in the Greater Toronto and Hamilton Area.

Two measures of accessibility are widely employed. Cumulative opportunity measures of accessibility compute how many opportunities an individual can reach within a predefined time threshold (Wickstrom, 1971), whereas gravity-based (or, equivalently, time-weighted cumulative opportunity) accessibility measures relax the assumption that people only travel until an arbitrary threshold, and discount opportunities by distance (or time) (Hansen, 1959). While gravity-based measures of accessibility more realistically reflect behavior, they require the prediction of a distance decay function and are thus more difficult to calculate, communicate, and compare across studies (El-Geneidy & Levinson, 2006).The concept of accessibility has been widely used to shed light on the benefits resulting from land use and transport systems. These benefits range from higher land values (El-Geneidy, van Lierop, et al., 2016), over smaller risks of social exclusion (Lucas, 2012), to shorter unemployment duration (Andersson et al., 2014; Korsu & Wenglenski, 2010) and increased odds of firm birth in areas with high accessibility levels (Holl, 2004). Furthermore, access by public transport has been shown to be related to increased transit mode share (A. Owen & Levinson, 2015a). Accordingly, to measure how these benefits are distributed across different socio-economic groups, accessibility measures have also been used to examine the equity of the transport and land use interaction (Bocarejo & Oviedo, 2012; Delmelle & Casas, 2012; Foth et al., 2013; Golub & Martens, 2014; Guzman et al., 2017). However, even though the connection between transport and economic development has been extensively investigated, insufficient research has coupled comprehensive measures of accessibility with urban development.

Accessibility is increasingly being incorporated into metropolitan transport plans and national planning guidelines, although mobility-planning remains the dominant paradigm (Boisjoly & El-Geneidy, 2017c; D. Proffitt et al., 2017). In the United Kingdom, a national accessibility framework exists, but analysis is still “generally too transport focused” and accessibility indicators are “misused” and “abused” (COST, 2012; Halden, 2011). At the municipal or regional scale, cities such as London, Paris, Sydney, and Atlanta are now employing the concept of accessibility, either as an independent goal or objective, or as part of an environmental justice assessment (Boisjoly & El-Geneidy, 2017a). In both Sydney and London, improving access to jobs or employment is mentioned as a key method to support regional economic development, and the ‘30-minute’ city is a key element to Sydney’s long-range plan (Greater Sydney Commission, 2018; NSW Government, 2012; Transport for London, 2006). Canadian cities, however, have been slow to adopt the concept; while their plans mention access *to* transit, only the discussion paper for the updated “Big Move” for Toronto contains a metric for access to jobs *by* transit, with goals similar to the London plan (Metrolinx, 2016). Similarly, in the United States, only a few cities have adopted accessibility goals and performance metrics in their regional transport plans (D. Proffitt et al., 2017). Accessibility planning practice thus remains limited across North America.

1.2 Transport, accessibility and urban development

A large body of literature has focused on establishing a theoretical framework between transport and subsequent land use patterns and urban development. Kain (1962) and later Alonso (1964) extended the model developed by von Thünen representing land value as a function of distance to a central business district, and argued that land values in turn influence land use patterns. The bid-rent theory developed by Alonso (1964), and later extended by many other scholars (see for example Anas and Moses (1977); Mills (1967)), offers households a trade-off between transport cost and rent, resulting in higher land values for more central locations. The area with the highest accessibility attracts the most development and becomes the CBD. In a self-reinforcing process, because it has greater access to both jobs and workers, competition will favor more intensive development in this central location, and according to bid-rent theory, prices will rise. Changes in the transport system are therefore said to result in changes in land use patterns through the intermediating effect of commute duration and land values.

In a similar vein as the urban economics scholars before them, transport researchers focusing on accessibility have linked transport changes to changing land use and activity patterns (El-Geneidy & Levinson, 2006; Forkenbrock et al., 2001; Giuliano, 2004). Many governments and transit agencies have also acknowledged the link between transport and economic development (European Commision, 2010), and many cities and regions worldwide are looking to capitalize on this link through land value capture (Medda, 2012; Salon & Shewmake, 2014; Smolka, 2013; Transport for London, 2017; Zhao et al., 2012).

Public sector policy, and economic and population growth, play vital roles in determining the viability of the links presented above (Giuliano, 2004; Warade, 2007). Supporting tax and land use policies, for example, can expedite how changes in accessibility impact land use, while the general economic climate is a vital aspect in determining whether or not development will occur on the site. Banister and Berechman (2000) argue that coordination between regional and municipal agencies, combined with favorable economic circumstances, are pre-conditions for the association between transport and development to occur.

The links presented above have subsequently been investigated in a myriad of empirical studies. Levinson (1998) examines the association between accessibility measures and commute duration. In a cross-sectional study, he finds that, for origins, access to employment opportunities is inversely related to average commute duration, while access to housing is positively correlated to average commute time. The association between accessibility and land values is considered by El-Geneidy, van Lierop, et al. (2016), Franklin and Waddell (2003) and Martínez and Viegas (2009), among others, who find that higher accessibility levels are related to increased home values. Iacono and Levinson (2015), on the other hand, conclude that, although homes in neighbourhoods with higher accessibility levels command value premiums, the relationship no longer holds for changes in accessibility. Maturity of the transport network is said to be causing this effect. Similarly, Du and Mulley (2006) find that the effects of accessibility on home values depend on location and the accessibility level of the neighbourhood.

The relationship between transport investments and economic benefits is assessed by Banister and Berechman (2000), Mejia-Dorantes et al. (2012), and Padeiro (2013), among others. They find that transport infrastructure changes are related to economic development, although the relationship varies by location and occurs mostly in sectors showing large agglomeration economies, such as finance and real estate. Mejia-Dorantes et al. (2012) show that distance to subway stations is a key determinant of firm location, while Padeiro (2013), in a case study of small municipalities in the Île-de-France region, concludes that the presence of train stations does not significantly affect job growth, whereas the presence of a highway is only a significant predictor of growth for the smallest municipalities.

Ozbay et al. (2003) investigate the relationship between accessibility and economic development in the New York – New Jersey region and find that accessibility changes are related to changes in employment growth (and therefore land use). Similarly, Alstadt et al. (2012) find that local accessibility calculated at a 40-minute threshold is a strong factor impacting economic activity in the service sector, while regional accessibility computed with a 3-hour threshold is more valued by the manufacturing sector. In a case study of motorways in Portugal, Holl (2004) develops a measure of market access similar to a gravity-based measure of access to the labour force, and concludes that the odds of firm birth are higher for several manufacturing and construction sectors when market access is larger. Applied to a case study in Chicago, Warade (2007) develops a quasi-integrated land use and transport model and concludes that higher access to jobs is associated with increased household density, whereas higher access to workers is related to increased job density. Y. Shen et al. (2014) examine the effects of local and regional accessibility on development near the Atocha station in Madrid, Spain. The authors find that accessibility, at both the city and country level, is a significant predictor in determining land cover change.

Farber and Grandez Marino (2017) acknowledge the strong association between accessibility and urban development, and generate a typology of planned stations in the Greater Toronto and Hamilton Area based on development potential around the station and the projected change in accessibility. The authors conclude that there exists considerable mismatch between development potential and large predicted accessibility changes from planned stations. This conclusion highlights the need for accessibility considerations when investing considerable amounts in new transport infrastructure, in order to realize the full benefits of the planned investment. We contend that the introduction of AOD can greatly benefit this process.

2. HYPOTHESES, DATA, AND METHODOLOGY

2.1 Hypotheses

Based on the theoretical accessibility and development framework and the empirical literature presented above, we hypothesise that accessibility drives the following natural phenomena:

Hypothesis 1: Residents in neighbourhoods with high access to employment opportunities and low access to workers experience the shortest average commute duration, and vice versa.

Hypothesis 2: Neighbourhoods with high accessibility levels to both employment opportunities and workers attract more development.

- *Hypothesis 2a: High access to workers draws in more businesses.*
- *Hypothesis 2b: High access to employment opportunities invites residential and commercial development by influencing home location choice and leveraging agglomeration economies.*

TABLE 5 - Summary of AOD hypotheses

Areas with:	High Access to Jobs	Low Access to Jobs
High Access to Labour	[Urban centre] H2a: Attracts employment and residences (commercial and residential development)	H1a: Residents have long commutes H2a: Attracts employment (commercial development)
Low Access to Labour	H1b: Residents have short commutes H2b: Attracts residences (residential development)	[Urban fringe]

Accessibility-oriented development invites planners to leverage access to steer, slow down, or speed up the phenomena that naturally follow from accessibility changes as presented in the hypotheses above. We therefore define accessibility-oriented development as a strategy that balances accessibility between employment opportunities and workers in order to foster an environment conducive to development. This differs from the traditional 'jobs-housing balance' literature by avoiding the use of arbitrary municipal boundaries and instead considers the relationship between access to jobs and access to competing workers (Cervero, 1989, 1996; Levinson, 1998; Levinson et al., 2017).

AOD will allow planners to leverage tools such as zoning measures to attract desired development into TOD sites. For example, assume that an area has been designated as a TOD site in planning documents. The zone can then become more attractive for commercial/industrial development – if the hypotheses above hold – by increasing access to the labour force, which can be achieved by (1) zoning a part of the proposed TOD as residential, to provide a direct customer/labour base, and (2) offering new and improving current transport options to a variety of residential neighbourhoods. AOD thus asks planners to leverage accessibility levels (in this case, increasing access to workers) to attract desired development (commercial and industrial in the case of the example).

In short, employing AOD in focus areas by increasing job accessibility should help shorten commute times and attract residents to these neighbourhoods, helping these regions to rejuvenate. Other areas could be designed to allow for maximum access to the labour force, which would provide incentives for firms in the service and retail sectors to locate themselves in these neighbourhoods, in order to minimize their employees' or customers' travel times and benefit from agglomeration economies. This in turn would lower commute times. Development would therefore occur naturally in sectors planned with AOD principles, once the starting conditions are set by adequate policy.

Ideally, TOD can be understood as a component of AOD. Whereas TOD solely focuses on local access/egress conditions *to* public transport and the local distribution of land use, AOD also considers access *by* public transport and the regional distribution of land use, as well as access to destinations by other modes.

2.2 Case study

To test the hypotheses about the phenomena that naturally follow from accessibility levels and thereby the validity of using an AOD approach, a case study is performed in the Greater Toronto and Hamilton Area, Canada (GTHA) between 2001 and 2011. The GTHA is the largest metropolitan agglomeration in Canada, housing 6.6 million residents in 2011 and comprises the Hamilton, Toronto and Oshawa census metropolitan areas (CMAs). Population in the region increased by over 1 million inhabitants during the study period, while the total number of jobs grew from 2.9 to 3.5 million (Statistics Canada, 2015). Between 2001 and 2011, the transport network in the region underwent substantial changes: a new subway line was opened in 2002, and several new train stations were constructed. A context map of the GTHA can be seen in figure 10.

Note that the choice of this particular case study is largely irrelevant in providing the foundations for an AOD approach. The case study only serves to corroborate that the two hypotheses about accessibility hold, even in a region where accessibility-oriented development tactics have not been employed. If, and only if, the hypotheses hold, AOD will be a valid strategy to develop sites or neighbourhoods.

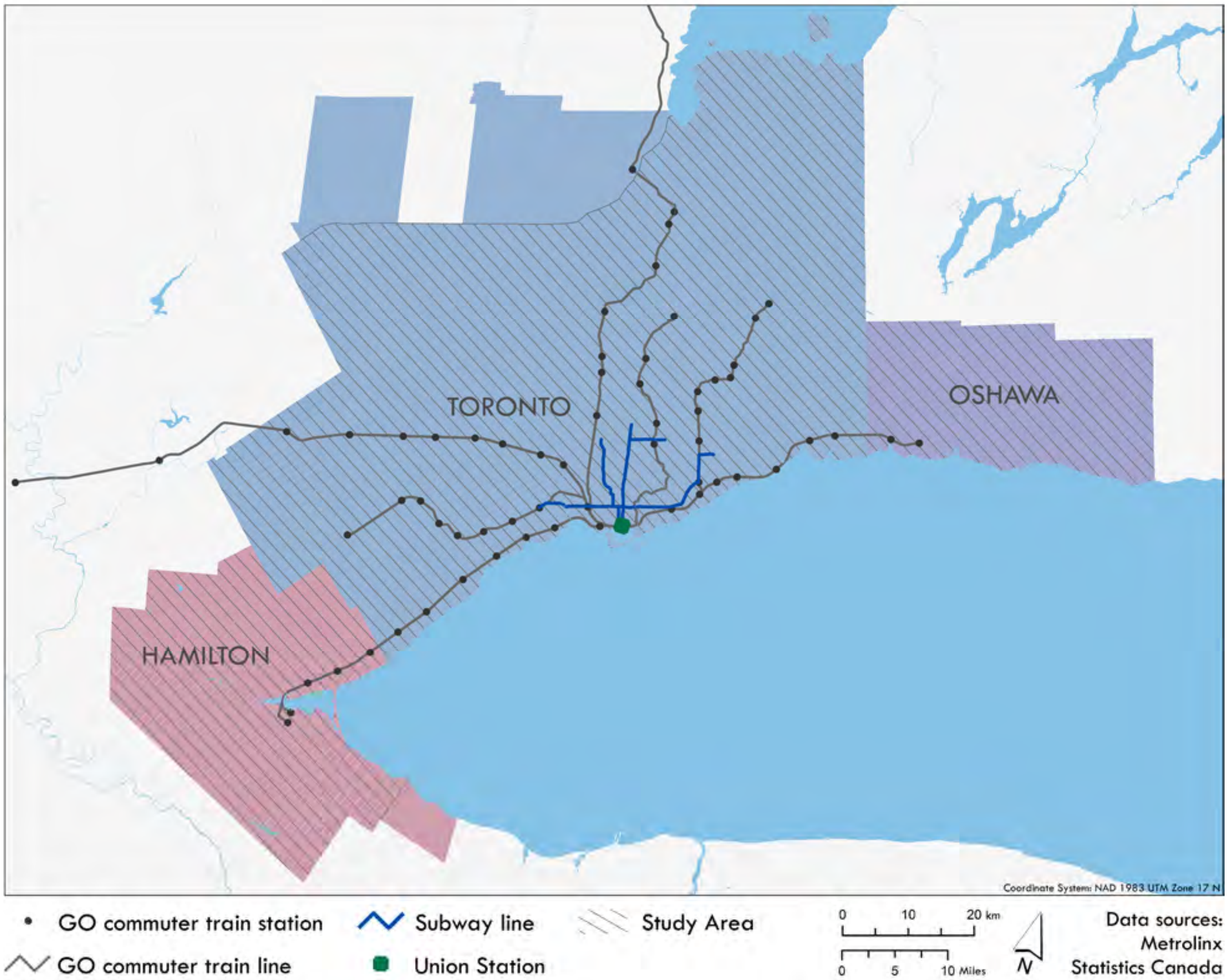

FIGURE 10 - Context map of the Greater Toronto and Hamilton Area

2.3 Data and Methods

To generate cumulative accessibility measures by both car and public transport (PT), data from Metrolinx and Statistics Canada were used. The cumulative opportunities metric was chosen because it is easier to communicate to planners and urban decision-makers, increasing its chances to impact policy (Geurs & van Wee, 2004; Handy & Niemeier, 1997). First, travel times between census tract centroids, modeled through the *EMME* software, by both car and public transport in 2001 were acquired from Metrolinx, in addition to car travel times in 2011. Public transport travel times in 2011 were subsequently calculated by making use of data from the General Transit Feed Specification (GTFS). A network was built based on this data in *ArcGIS* through the tool *'Add GTFS to a network dataset'*, and fastest routes were calculated between each census tract centroid on a regular Tuesday at 8 AM in 2011. The fastest path algorithm took into account walking time, waiting time, and in-vehicle time (as determined by the transit schedule), but did not assign a penalty for transfers. Census data provides the number of jobs and the population in the labour force in each census tract.

To reflect the commuting behavior of an average individual, car accessibility was calculated for a time threshold of 30 minutes (equivalent to the average commute duration in the region by car), while access by transit was computed for a 45 minute time threshold (equivalent to the average commute duration in the region by public transport (Statistics Canada, 2010)). A cumulative measure of accessibility then counts the number of opportunities that can be reached within that threshold. As the data sources for the number of jobs differed between 2001 and 2011, a relative measure of accessibility was calculated by dividing the total number of jobs (workers) reachable within the threshold by the total number of jobs (workers) in the region. Accessibility can then be interpreted as the percentage of all jobs (workers) in the region an individual can access: a value of 1 signifies that all jobs (workers) can be reached within the threshold (30 or 45 minutes depending on the mode), while a value of 0.25 indicates that 25% of all jobs (workers) can be reached within the set time frame. The accessibility calculations were performed for each census tract in the GTHA.

To test the two AOD hypotheses, commute duration for 2011 was gathered from Statistics Canada, while commute duration in 2001 was calculated based on travel times and origin-destination flows provided by Statistics Canada. Development was subsequently measured by the change in the percentage of open area in the census tract (measured as the area not used for residential, commercial, industrial, governmental, or park purposes). The AOD hypotheses were then examined through five regression models, relating commute duration, open area, and job and population density with accessibility and accessibility changes.

A first, cross-sectional, model predicts average commute duration in 2001 based on accessibility in 2001 and a dummy variable for the Hamilton CMA. A dummy variable for Hamilton was introduced to reflect that residents of census tracts in the Hamilton CMA are more likely to commute to Hamilton than Toronto, thus their commute time is, on average, lower than in the Toronto or Oshawa census metropolitan areas.

A second model, to test if the relationship between commute duration and accessibility also holds over time, predicts commute time in 2011 based on observed commute times in 2001 (by car and public transport combined) and accessibility in 2001, as well as changes in accessibility levels between 2001 and 2011. Levels of accessibility in 2001 were included as it is assumed that the initial situation will influence how changes occur (Putnam, 1983). Model 1 and 2 together thus examine the link between accessibility and commuting behavior, in order to validate our first AOD hypothesis, namely that inhabitants of AOD areas with high access to jobs and low access to the labour force experience the lowest commute times.

A third model was developed to assess the second AOD hypothesis, with open area acting as a proxy for development. Open area was measured as the area not used for residential, commercial, industrial, governmental, or park purposes. The same model specification as the second model is used: open area in 2011 is predicted based on open area and accessibility in 2001, and changes in accessibility between the two years. In order to disentangle the separate effects of labour and employment accessibility on attracting residential, commercial, and industrial development, two extra regressions were performed: one predicting job density and the other predicting population density in 2011. Descriptive statistics of the variables used in the different models are shown in Table 6.

TABLE 6 - Descriptive statistics for commute duration, accessibility and development data

Variable	Description	Mean	Standard dev.
Commute01	Average commute time in 2001 (min) (all modes)	28.58	6.55
Commute11	Average commute time in 2011 (min) (all modes)	31.29	4.25
Access01 to Jobs by Car	Access to jobs by car in 30 minutes in 2001 (%)	20.12	12.25
Access01 to Workers by Car	Access to workers by car in 30 minutes in 2001 (%)	20.75	6.86
Access01 to Jobs by PT	Access to jobs by PT in 45 minutes in 2001 (%)	8.90	9.97
Access01 to Workers by PT	Access to workers by PT in 45 minutes in 2001 (%)	7.53	6.79
Access11 to Jobs by Car	Access to jobs by car in 30 minutes in 2011 (%)	30.97	20.24
Access11 to Workers by Car	Access to workers by car in 30 minutes in 2011 (%)	29.26	10.36
Access11 to Jobs by PT	Access to jobs by PT in 45 minutes in 2011 (%)	8.17	8.62
Access11 to Workers by PT	Access to workers by PT in 45 minutes in 2011 (%)	6.32	5.20
Δ Commute	Change in commute time (min) (all modes)	2.71	4.70
Δ Access to Jobs Car	Change in access to jobs by car (%)	10.84	10.17
Δ Access to Workers by Car	Change in access to workers by car (%)	16.74	7.59
Δ Access to Jobs by PT	Change in access to jobs by PT (%)	-0.73	3.34
Δ Access to Workers by PT	Change in access to workers by PT (%)	-1.21	2.67
OpenArea01	Percentage of open area in 2001 (%)	14.61	15.92
OpenArea11	Percentage of open area in 2011 (%)	14.57	24.13
JobDens01	Job density in 2001 (jobs/km^2)	181.45	526.07
JobDens11	Job density in 2011 (jobs/km^2)	164.64	544.94
PopDens01	Population density in 2001 (population/km^2)	4337.34	4781.05
PopDens11	Population density in 2011 (population/km^2)	4903.45	5285.02

3. RESULTS AND DISCUSSION

Figure 11 shows normalized accessibility levels by car to employment opportunities and workers. Access to jobs by car is highest in downtown Toronto, while the highest accessibility levels to workers are present in neighbourhoods that form a ring around the Toronto CBD. This reflects that the central business district houses fewer people than the area immediately surrounding it, and that it is easier for residents of the outskirts of the region to travel to these suburban locations than to the city centre. Between 2001 and 2011, access to workers increased substantially more across the study area than access to jobs. According to the second AOD hypothesis, the suburban locations with high access to the labour force should experience more job creation during the study period, providing that the benefits of access to labour outweigh those of existing agglomeration economies of access to existing businesses (operationalized as access to jobs).

Accessibility levels by public transport are shown in figure 12. Access by transit is considerably lower than access by car, even with an extra 15 minutes of travel time, in both years, for access to jobs and workers. High access by transit is mainly present in downtown Toronto and in areas located in close proximity to the commuter rail lines. Unlike the spatial patterns present in access by car, the two accessibility measures for public transport, to jobs and workers, are highly correlated (a correlation of 0.95). In 2011, suburban areas located next to the public transport network have seen increases in accessibility, while areas with traditionally high access (such as downtown Toronto) have seen a small decrease in access, which might be related to an ongoing suburbanization of jobs, combined with investments made in the commuter train network during the study period.

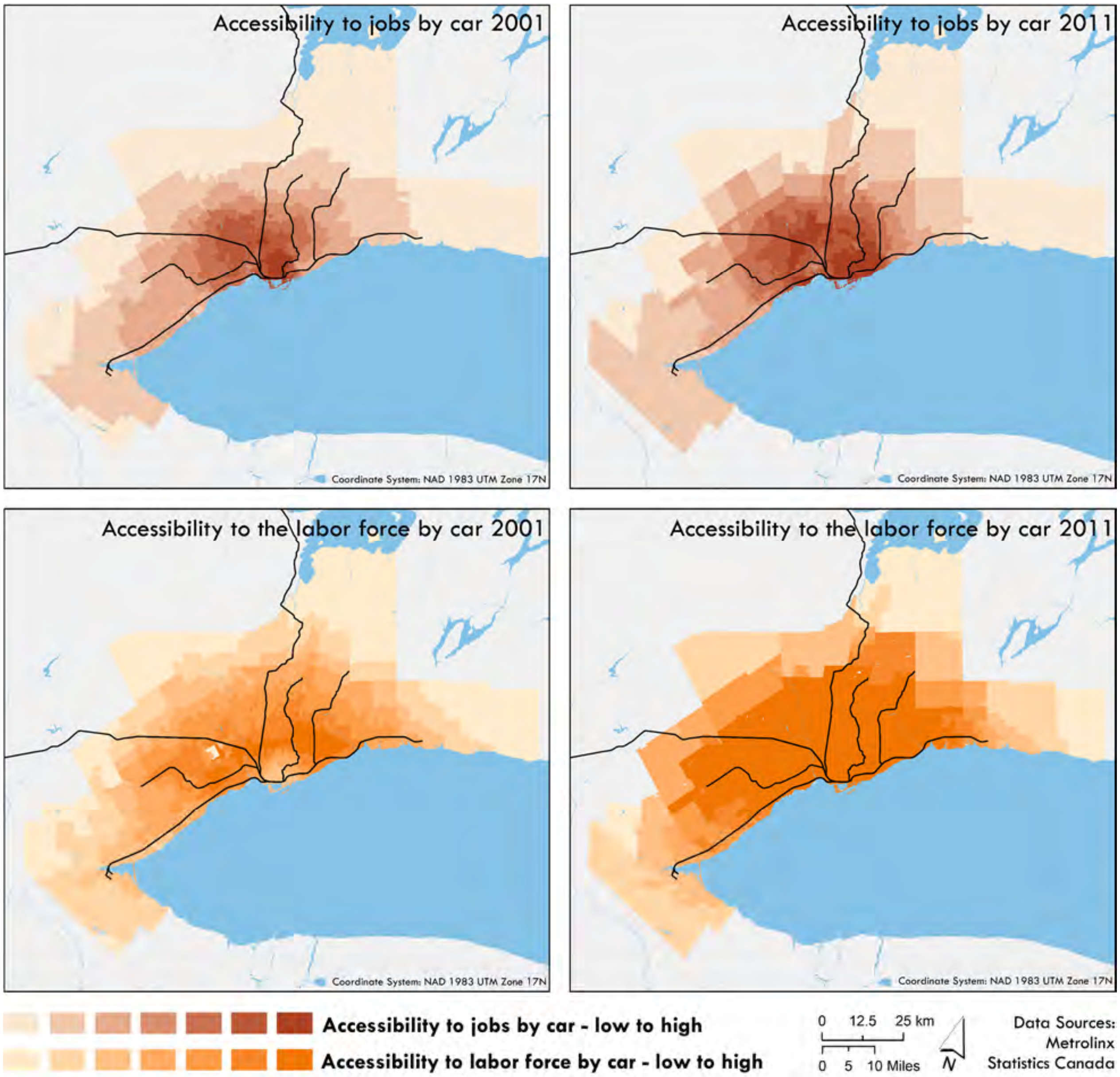

FIGURE 11 - Access to jobs and the labour force by car within 30 minutes

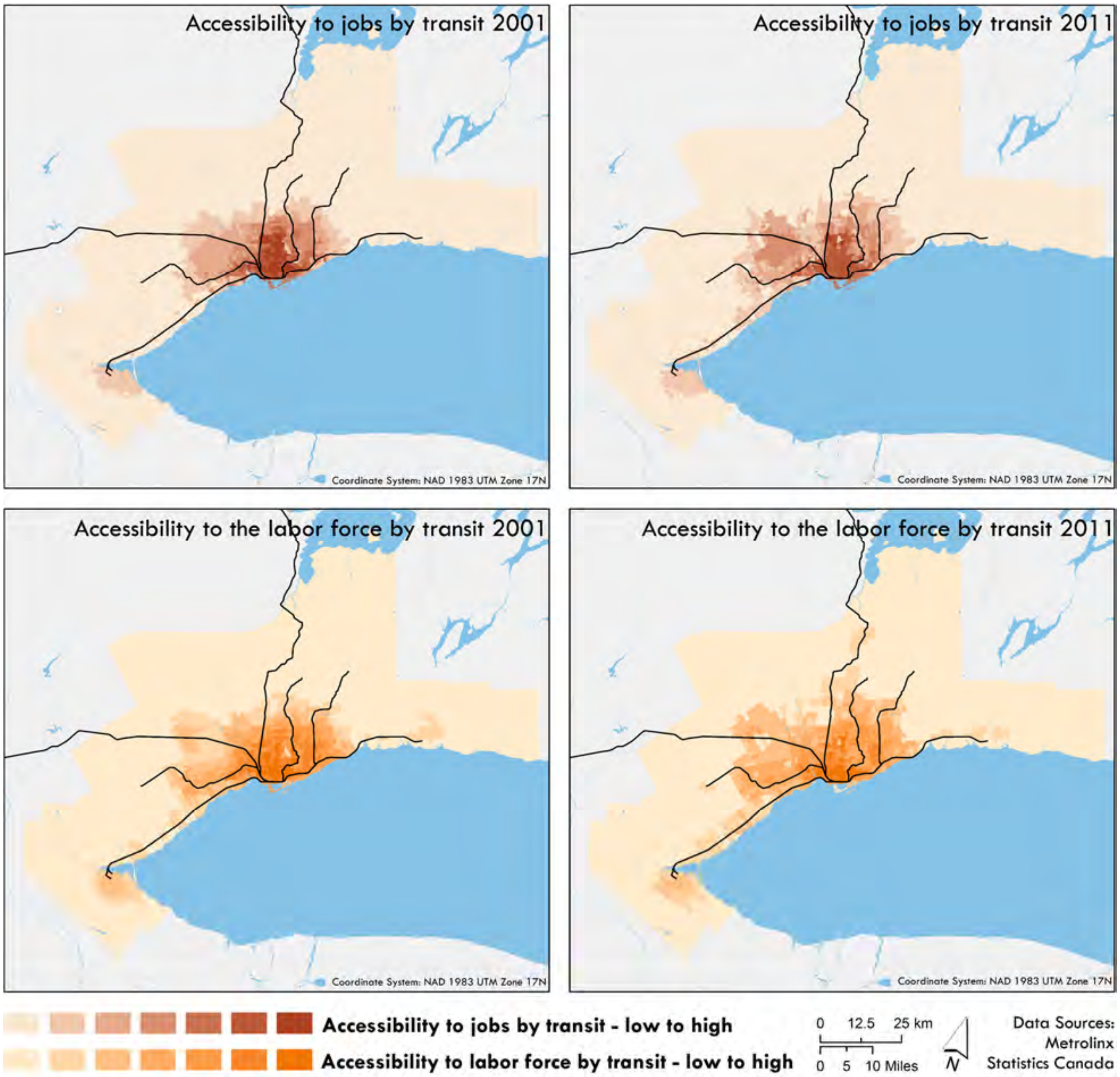

FIGURE 12 - Access to jobs and the labour force by public transport within 45 minutes

3.1 Accessibility, commute duration and urban development

The results of the model associating average commute duration in 2001 and accessibility (Model 1) are shown in Table 7. Note that access by public transport was not included in this model due to collinearity with access by car. A separate model was tested for public transport accessibility and resulted in similar conclusions, but was excluded from the analysis due to its similarity with the reported model.

Higher access to jobs is related to shorter commute times, ceteris paribus, while a higher access to the labour force is related to longer commute times, all else equal, which is consistent with the findings from Levinson (1998). In absolute terms, an extra 100,000 accessible jobs decreases commute time by 0.48 minutes (-0.14 minutes per percent), while an extra 100,000 workers increases average commute duration by 0.87 minutes (0.27 minutes per percent). These results corroborate the first AOD hypothesis: AOD areas with high access to jobs and low access to the labour force have shorter average commute times than the rest of the region (and vice versa).

The dummy variable for Hamilton indicates that, all else equal, commute time in the Hamilton census metropolitan area is 6.4 minutes shorter. Note that accessibility levels also influence the predicted commute duration in Hamilton. Evaluated at the average accessibility levels for Hamilton (9% of all jobs accessible by car and 12% of all workers accessible by car), census tracts in Hamilton have an average predicted commute duration of 22.2 minutes, 7.2 minutes less than the predicted average for the entire study area.

TABLE 7 - Regression model predicting average commute duration in 2001

Variable	Coefficient	Sig.	Confidence int.†	Hypothesis
Intercept	26.5799	***	[25.3558, 27.8040]	
Access01 to Jobs by Car	-0.1411	***	[-0.1699, -0.1124]	-
Access01 to Workers by Car	0.2722	***	[0.2178, 0.3265]	+
Hamilton dummy	-6.3950	***	[-7.4930, -5.2971]	-
Adjusted R^2			0.2212	

Dependent Variable: Average commute duration in 2001
* 95% significance level | ** 99% significance level | *** 99.9% significance level
† 95% confidence interval

The results of the temporal model relating commute time and accessibility (Model 2) are shown in Table 8. Almost 60% of the total variation in commute times in 2011 is explained by this model. The coefficients for accessibility in 2001 have the expected signs and statistical significance: access to jobs in 2001 is associated with a shorter commute time, while access to the labour force is related to a longer commute duration. The statistical significance of both coefficients could be related to a time lag between accessibility levels and commute patterns adjusting themselves to the new situation, i.e., commute patterns in 2001 were not yet in equilibrium with respect to 2001 accessibility.

Unlike in the cross-sectional model, the effects of both changes in access by public transport and car can be investigated separately, as their changes are no longer correlated. Notably, only changes in access to workers by car and access to jobs by public transport are statistically significant predictors of average commute duration in 2011. These results confirm that the first AOD hypothesis also holds over time. An increase in the change in accessibility of 1% of all workers by car lengthens commutes by 0.2 minutes, while a 1% increase in access by public transport to all jobs reduces commutes by 0.1 minutes. Interestingly, the relative magnitudes of both coefficients are reversed compared to the cross-sectional model.

The two coefficients for change in access to jobs by car and to workers by public transport were found to be not statistically significant. We hypothesize that this is related to the maturity of the transport network in the region. Small changes to the network can no longer induce large impacts on accessibility levels (Gómez-Ibáñez, 1985), resulting in diminishing returns to the outcomes of transport investments (Iacono & Levinson, 2015).

TABLE 8 - Commute time and open area in 2011 fitted to accessibility in 2001 and changes in accessibility between 2001 and 2011

	Commute duration in 2011				Open area in 2011			
Variable	**Coeff.**	**Sig**	**Confidence int.** †	**Hyp.**	**Coeff.**	**Sig**	**Confidence int.** †	**Hyp.**
Intercept	17.8976	***	[17.0579, 18.7372]		21.3201	***	[17.9573, 24.6829]	
Access01 to Jobs by Car	-0.1027	***	[-0.1250, -0.0804]	-	-0.1948	**	[-0.3185, -0.0710]	-
Access01 to Workers by Car	0.0793	***	[0.04652, 0.1122]	+	-0.6212	***	[-0.8162, -0.4262]	-
Δ Access to Jobs Car	-0.0093		[-0.0306, 0.0121]	-	0.0251		[-0.0989, 0.1490]	-
Δ Access to Workers by Car	0.2139	***	[0.1745, 0.2532]	+	-0.0595		[-0.2875, 0.1685]	-
Δ Access to Jobs by PT	-0.1083	***	[-0.1713, -0.0453]	-	0.2876		[-0.0810, 0.6561]	-
Δ Access to Workers by PT	-0.0652		[-0.1558, 0.0254]	+	-0.6645	*	[-1.1883, -0.14075]	-
Commute01 (Observed)	0.3561	***	[0.3295, 0.3826]	+				
OpenArea01					0.4958	***	[0.4633, 0.5282]	+
Adjusted R^2			0.5922				0.5459	

Dependent Variables: Average commute duration and open area in 2011
* 95% significance level | ** 99% significance level | *** 99.9% significance level
† 95% confidence interval

The results for the model predicting the percentage of open area in each census tract in 2011 (Model 3) can be seen in Table 8, explaining 55% of all variation in open space. The statistically significant coefficients for accessibility in 2001 corroborate the second AOD hypothesis: access to jobs and workers in 2001 are associated with decreases in open area. One extra percent of access to jobs by car in 2001 reduces open space by 0.19%, and an extra percent of access to workers decreases open space 0.62%. Residential, commercial, and industrial development thus seems to be associated with AOD areas.

Changes in accessibility levels, except for the change in worker access by public transport, are not statistically significant predictors of open space in 2011. Two explanations are possible. First, location choices do not occur often due to the associated capital costs, thus there exists a substantial time lag between accessibility levels changing and location choice. A study period encompassing only 10 years will therefore not be able to fully capture these long-term decisions, especially as it is unknown when each accessibility change occurred. It is also expected that firms, rather than individuals, are more sensitive to changes in access to jobs and workers, and are more prone to change their locations (as residents also place high value on access to other opportunities, such as schools, shops, and social networks). The statistically significant coefficient for the change in access to workers by transit corroborates this, as it is expected that access to workers is an attractor in firm location behavior. As only the change in access to workers by public transport is statistically significant, we can conclude that firms in the GTHA are more likely to locate near areas where transit service, instead of car accessibility, increases. Although this relationship might depend on the business sector and their associated transport costs for their products and employees, it could be indicative of a paradigm shift in the way (some) enterprises expect their employees or customers to travel. Second, as some areas are almost fully built, changes in accessibility in these neighbourhoods can no longer reduce open space and can therefore not be captured by the model.

To resolve this second possibility, and to confirm the hypotheses about firm and individual behavior mentioned above (hypotheses 2a and 2b), two extra models were computed, predicting job and population density in 2011, see Table 9. These models again confirm the second AOD hypothesis: job density increased more in areas where baseline access to workers was highest, whereas population density grew considerably more in areas where 2001 access to jobs was highest. This corroborates the hypothesis that firms are attracted to where workers and customers are located, whereas individuals are more likely to choose a home with high access to job opportunities.

Surprisingly, access to jobs in 2001 is not significant in the model predicting job density and has a negative coefficient, indicating that businesses were more likely to locate away from existing jobs. When a squared term of this variable is added to the model, the relationship follows a more intuitive pattern, although it is still insignificant: once there is critical mass of job accessibility, businesses are attracted to job-rich areas, corroborating the importance of agglomeration economies. Furthermore, this research uses a crude measure of ‘jobs’, implicitly assuming all jobs are equivalent. While some jobs are in agglomeration-favoring industries (like finance and government), others need to be near, but not central to, agglomerations (like industry), or near customers (retail, services).

Among the change variables, only the change in access to the labour force by transit is statistically significant: a 1 percent increase in access to workers by public transport between 2001 and 2011 is associated with an extra 8 jobs per square kilometer. As with the model predicting open area, it appears that firms in the region were more likely to be attracted to areas where the public transport system, instead of the highway and street network, improved.

The model predicting population density in 2011 shows that all changes in accessibility, except for the change in access to jobs by transit, are statistically significant. The two coefficients for the change in access to the labour force by car and transit are positive, suggesting that individuals are attracted to locations where worker accessibility increased during the study period. Note that the significance of these variables could be related to reverse causality: as job-rich areas attract more residents, worker accessibility will necessarily increase in and surrounding these areas. The change in population density in the neighbourhood and in surrounding census tracts might therefore cause the change in worker access. The coefficient for the change in access to jobs by car is negative and thus contradicts our hypothesis: an increase in job accessibility of 1% between 2001 and 2011 is related to a decrease in population density of 23 inhabitants per km^2. This might, however, indicate a trade-off between residential and commercial development in a census tract, or might be related to larger scale zoning patterns that do not allow concurrent residential and commercial development in a single zone. Nevertheless, the significance and signs of the majority of the variables in the model corroborate the second hypothesis.

TABLE 9 - Job and population density in 2011 fitted to accessibility in 2001 and changes in accessibility between 2001 and 2011

	Job density in 2011				Population density in 2011			
Variable	**Coeff.**	**Sig**	**Confidence int. †**	**Hyp.**	**Coeff.**	**Sig**	**Confidence int. †**	**Hyp.**
Intercept	-31.9827	*	[-62.2608, -1.7045]		81.3165		[-379.6737, 542.3068]	
Access01 to Jobs by Car	-1.2361		[-2.5445, 0.0724]		21.3944	*	[1.9579, 40.8308]	+
Access01 to Workers by Car	2.1506	*	[0.1992, 4.1020]	+	-21.9910		[-51.3465, 7.3645]	
Δ Access to Jobs Car	0.4887		[-0.7560, 1.7333]		-23.0279	*	[-41.8525, -4.2032]	+
Δ Access to Workers by Car	-0.0960		[-2.3794, 2.1874]	+	67.2478	***	[32.6678, 101.8279]	
Δ Access to Jobs by PT	-1.6380		[-5.3603, 2.0844]		-37.1115		[-93.4974, 19.2743]	+
Δ Access to Workers by PT	8.4400	**	[3.2029, 13.6772]	+	174.8577	***	[95.6686, 254.0467]	
JobDensity01	1.0042	***	[0.9853, 1.0231]	+				
PopDensity01					0.9584	***	[0.9259, 0.9909]	+
Adjusted R^2			0.931				0.787	

Dependent Variables: Average commute duration and open area in 2011
* 95% significance level | ** 99% significance level | *** 99.9% significance level
† 95% confidence interval

4. CONCLUSION

Accessibility-oriented development, both a market process and a strategy that aims to balance accessibility between employment opportunities and workers in order to foster an environment conducive to development, has been shown to be associated with changing commute times and economic development. Through AOD planners can leverage the relationship between transport and land use patterns by explicitly considering the functional connections between local and regional transport investments and local and regional land use. In contrast with TOD, AOD also considers the access that is provided *by* transit, instead of only examining access *to* transit.

The regression models in our study indicate that, through AOD, planners can capitalize on two tangible benefits that accrue to neighbourhoods when accessibility levels change. First, by influencing access to jobs and/or workers through land use (e.g. zoning) or transport changes, average commute times can be adjusted across neighbourhoods: increases in access to jobs are related to decreases in commute duration, while increases in access to workers are associated with longer average commute times. Second, higher access to jobs and/or workers is associated with residential, commercial, and industrial development.

It is important to note that the relationships uncovered in this study are not conclusive, nor can they determine a causal relationship; more studies would need to be developed in multiple cities to further corroborate these findings. Furthermore, the analyses conducted in this study were performed under the assumption that the land market in the GTHA operates in perfect market conditions. Toronto, however, as with most cities in the world, regulates and prioritizes certain land uses in their many plans and programs, potentially altering the effects of accessibility on location choices in favor of the city's development guidelines.

Nevertheless, this study provides strong evidence of the relationship between accessibility, commute duration, and residential and firm location. Planners and urban decision-makers aiming to create successful developments should therefore not limit themselves to using site-specific planning tools such as TOD, but should also take into account AOD principles, by measuring the impacts of new transport or land use plans in terms of access to both employment opportunities and workers, and then leveraging these accessibility levels to generate desired development.

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CONCLUSION

Accessibility is increasingly being used in both research and practice as a key performance indicator for integrated land use and transport planning. Many cities around the world, in their respective transport plans, have now adopted the concept and intend to increase access to destinations to reduce social exclusion and provide a catalyst for economic growth.

Among Canada's eleven largest metropolitan areas, Toronto residents experience the highest access to jobs, followed by those in Montréal, Vancouver, Calgary and Ottawa. When examining access to low-income jobs, however, vulnerable inhabitants of Montréal are much better off than in any other Canadian city. Overall, vulnerable individuals experience higher accessibility levels than their fellow residents in their respective cities, indicating that accessibility is equitably distributed in Canada's largest metropolitan areas. However, poverty is slowly being suburbanized as city centres and neighbourhoods next to transit hubs are increasingly being re-developed and re-vitalized. The most vulnerable households might therefore be pressured to move to areas where accessibility is (much) lower than in their previous locations, which could negatively affect vertical equity in many of Canada's large cities.

Government policies intending to increase accessibility in socially-vulnerable neighbourhoods can bring considerable benefits to these areas. The results from chapter 2 suggest that, for low and medium income census tracts, increases in transit accessibility are related to higher increases in income. An improvement in accessibility to jobs by car is similarly associated with larger income increases. Furthermore, unemployment rates rose less in areas where accessibility levels improved. The equity of accessibility to employment opportunities thus plays a key role in determining resulting equity of outcome, stressing the need for methods that can incorporate equity considerations into the evaluation of new transport projects.

The results from chapter 3 suggest that accessibility improvements can also create considerable economic benefits: increases in accessibility to jobs and/or workers in the Greater Toronto and

Hamilton Area were associated with more residential, commercial, and industrial development. Moreover, accessibility levels influenced commute durations: high accessibility to jobs was related to shorter commutes and higher accessibility to people was associated with longer commutes.

By embracing policies to increase accessibility levels, cities can thus improve quality of life for their most vulnerable inhabitants while at the same time attracting economic development. Cities and their transport planning agencies can therefore greatly benefit from adopting accessibility indicators and incorporating these into their plans and policies.

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