Elevating access: Comparing accessibility to jobs by public transport for individuals with and without a physical disability

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ABSTRACT

Equal access to opportunities has emerged in public transport planning as a social objective that many transport agencies are trying to achieve. Yet in practice, not all public transport agencies are currently providing urban residents with comparable levels of service due to physical barriers in the public transport network that can significantly hinder the ability of individuals with physical disabilities to access opportunities. In countries without a strong federal accessibility act and/or with major financial constraints, some public transport agencies fall behind in applying universal access design principles, making it even harder for people with a physical disability to access opportunities. The objective of this study is to develop a methodology that can be used by public transport agencies or disability advocates to clearly highlight and quantify the performance of the public transport network in a region, in terms of providing transit services to people in a wheelchair and compare that to the service offered to an individual not in a wheelchair. In this study we use accessibility, the ease of reaching destinations, by public transport as the key performance measure in two major Canadian Cities (Montreal and Toronto). Furthermore, we focus on job accessibility in the most socially vulnerable census tracts in both cities, to evaluate levels of job accessibility for wheelchair users residing in socially vulnerable areas. The findings from our study show striking contrasts between the numbers of accessible jobs by public transport for wheelchair users compared to the general population. On average, wheelchair users in Toronto have access to 75% of jobs that are accessible to users that are not in a wheelchair, whilst their counterparts in Montreal have access to only 46% of the jobs accessible to other users. This research is expected to highlight for public transport engineers, planners, policy makers and advocates for those with disabilities, the importance of universal access in a region, especially along public transport networks, using a widely used land use and transport performance measure.

Keywords: Equity, Disabled access, Job accessibility, Travel time.

INTRODUCTION

Accessibility, the ease of reaching destinations, is a key land use and transport performance measure (Hansen, 1959) that has been used in various studies to assess the equitable distribution of public transport service in a region (Bocarejo & Oviedo, 2012; Foth, Manaugh, & El-Geneidy, 2013; Golub & Martens, 2014; Guzman, Oviedo, & Rivera, 2017; Manaugh & El-Geneidy, 2012). Low accessibility to jobs has been shown to be related to higher risks of unemployment, especially in low-income areas (Korsu & Wenglenski, 2010). Furthermore, the absence of public transport in a neighborhood, even temporarily, can significantly impact unemployment rates in areas where people depend on it to reach their desired destinations (Matas, Raymond, & Roig, 2010; Sari, 2015; Tyndall, 2015).

Despite the gradual emergence of social equity goals in urban transport plans (Manaugh, Badami, & El-Geneidy, 2015), many cities do not deliver public transport services that provide adequate levels of accessibility to jobs for all neighborhoods and thus not all residents benefit from comparable levels of service (Martens, 2012). Previous studies that looked at accessibility and equity mostly concentrated on equity of the public transport system, with the assumption that all residents in a region can use public transport. Whilst in reality the public transport network that is available for a person in a wheelchair can be significantly different from the network available to the rest of the population, due to physical barriers such as stairs in subway stations or inaccessible buses. Such barriers and the associated difficulty with reaching employment opportunities impose significant challenges on a vulnerable group of people that have been found to be more likely to be unemployed or underemployed compared to the general population for a considerable time (BC Stats, 2009; Benoit, Jansson, Jansenberger, & Phillips, 2012; Lillie, Alvarado, & Stuart, 2013; Statistics Canada, 2016).

To our knowledge, no previous study has considered the physical barriers present in a public transport network when measuring accessibility to jobs by public transport. Accordingly, this study presents a methodological approach to assess the level of accessibility to jobs using public transport for wheelchair users in the City of Toronto and the Island of Montreal, Canada on a typical weekday during the morning peak. We then contrast this level of accessibility with that of the general population, who we assume are able to access the entire public transport network. In particular, we examine job accessibility experienced by wheelchair users and the general population in the most socially vulnerable census tracts in both cities. The methodology used in

this study can benefit transport planning agencies aiming to promote public transport equity based on service supply and provision for wheelchair users. The results generated can be easily communicated to policy makers and to the public as they are expressed in the number of jobs that can be reached within a certain travel time by public transport. The results also provide insights on how to effectively improve accessibility to jobs by public transport for wheelchair users, which will be beneficial to the wider population, namely older adults, and individuals traveling with luggage or a stroller. Against the backdrop of the progression of the Canadians with Disabilities Act, this study is aptly timed to demonstrate the degree of disparities in accessibility between wheelchair users and the general population and presents recommendations for how to reduce disparities in accessibility levels in both the long-term and short-term. The methodology presented in this study is highly relevant to other contexts with similar issues in physical access that are present in older public transit networks.

This paper is organized in five sections. The first introduces the concepts of accessibility, equity and universal design within the academic sphere before progressing to an overview of the disability legislation within Canada. The second presents the Toronto and Montreal study contexts, followed by a description of the data and methodology used. Results are then presented and analyzed spatially for both wheelchair users and the general population. We then produce an accessibility ratio to highlight the locations where the disparities between accessibility for wheelchair users and the general populations are substantial, and identify socially vulnerable neighborhoods that are particularly affected by disparities in job accessibility levels. Finally, the results are discussed and the recommendations and conclusions of the study are presented.

LITERATURE REVIEW

The literature review section will commence with a discussion of accessibility measures and their inclusion in land use and transport planning, in addition to social equity. This will be followed by a brief discussion of universal access and its importance for people with a disability. Finally, the literature review will include a discussion of the disability legislation in Canada to guide the reader in understanding the legislation in the local context, which has likely contributed to the current situation in the public transport systems in the studied Canadian cities.

Defining Accessibility

Accessibility is defined as a measure of potential opportunities (Hansen, 1959). One commonly used measure of accessibility is known as cumulative opportunities, where within a given time thresholds (usually 30 or 45 minutes), the number of opportunities that can be accessed using a given travel mode is measured. Within many studies in practice, the 'opportunities' measured are jobs, although in theory there are an infinite number of other opportunities that could exist, such as health clinics, hospital emergency departments, educational institutions and retail outlets (Geurs & van Wee, 2004; Vickerman, 1974). This measure considers all opportunities equal and excludes those that are beyond the defined threshold, hence not considering the travelers' perceptions of time (Ben-Akiva & Lerman, 1979). An alternate measure of accessibility is the gravity-based measure, which discounts the desirability of the opportunities that are further away, meaning that the closest opportunities to the origin carry more weight (Geurs & van Wee, 2004; Handy, 1994; Hansen, 1959; Owen & Levinson, 2014; Vickerman, 1974). This measure more closely follows travel behavior theory, yet the results can be more difficult to communicate to the public. Gravity-based and cumulative accessibility measures have been found to be highly correlated, which enables researchers to use either model as necessary (El-Geneidy & Levinson, 2006; Manaugh & El-Geneidy, 2011). We have therefore opted for a cumulative opportunity model in this study, due to its ease in communication.

Determining accessibility by public transport is an effective tool to evaluate the distribution of services in a region, particularly to assess how the transport system benefits different populations (Foth et al., 2013; Pucher & Renne, 2003; Sanchez, Shen, & Peng, 2004). Equity within transport studies often refers to the fairness of the distribution of transportation costs and benefits (Martens, 2017). However, defining what is a fair distribution of the associated costs and benefits is an elusive concept in the transport literature. For the purpose of this study, a measure of equality is adopted, whereby all individuals deserve equal levels of accessibility. In other words, individuals in a wheelchair require at least the same levels of accessibility as the general population residing in the same location. The need to deliver equal levels of service to all individuals has been adopted within universal design principles, which would in theory ensure that wheelchair users would have equal levels of accessibility as the general population residing in the same location.

Comparing the level of accessibility between those in a wheelchair and the rest of the population has previously been developed in an indoor retail context (Hagg & El-Geneidy, 2010).

To our knowledge, however, accessibility tools have not been used to measure these differences in job accessibility using public transport.

Universal Design

The concept of universal design aims to provide all individuals with or without disabilities in a region with the right to access and use the same public systems at the same level of service (Evcil, 2009; Imrie & Kumar, 1998). According to the principles of universal design, obstructions such as stairs, heavy doors, steep ramps, and poor signage/lighting should be minimized, to develop an environment that is truly open and functional to everyone (Bromley, Matthews, & Thomas, 2007). Despite the efforts of public organizations and advocacy groups, the current public transport system in many high-income countries does not meet the basic standards for universal design. The built environment, including the transport system is usually designed for the perceived model user, which is young and able bodied (McMillen, 2001). This is a major issue since a growing percentage of the population is aging and acquiring disabilities as they age. According to the 2012 statistics, about 14% of the Canadian population has some sort of physical disability (Statistics Canada, 2016). Lack of universal design can be just as disabling as a physical condition, which denies people with physical disabilities the same levels of access as people without disabilities (Evcil, 2009; Kitchen & Law, 2001). Over two-thirds of respondents to a survey about disability reported that the society was their main cause of disability, not their physical impairment (Bromley et al., 2007). As a result of the importance of universal access, in the 1990s several governments such as the United States and the United Kingdom passed disability legislations ensuring equal access to all individuals, which required public agencies to ensure that all their facilities are accessible to all individuals. In Canada such legislation does not exist at the federal level, and in the absence of a federal disabilities act, the rights of disabled Canadians and obligations of public agencies including public transport organizations, is reserved to provincial government acts.

Disability Legislation in Canada

In the absence of a federal disabilities act with enforceable physical access standards, such as the Americans with Disabilities Act of 1990 (ADA) in the United States, the decision to enact disability legislation to ensure public agencies and businesses provide equal access to all individuals lies at the hands of individual provinces, although the majority have no such legislation. The Ontario

legislation currently in place is the *Accessibility for Ontarians with Disabilities Act, 2005 (OADA)*, whose stated purpose is as follows:

> *"the purpose of this Act is to benefit all Ontarians by*
> *(a) developing, implementing and enforcing accessibility standards in order to achieve accessibility for Ontarians with disabilities with respect to goods, services, facilities, accommodation, employment, buildings, structures and premises on or before January 1, 2025. (Government of Ontario, 2005)"*

The equivalent Quebec legislation is the *Act to secure handicapped persons in the exercise of their rights with a view to achieving social, school and workplace integration, 2004.* The stated objective of this act is as follows:

> *"The objective of this Act is to secure handicapped persons in the exercise of their rights and, through the involvement of government departments and their networks, municipalities and public and private agencies, to help them integrate into society to the same extent as other citizens by providing for various measures to apply specifically to handicapped persons and their families, their living environments and the development and organization of resources and services for them.*
> *To that end, this Act aims to enable the Office to efficiently carry out its role in assessing the integration of handicapped persons, to ensure compliance with the principles and rules of this Act and to play a decisive role in providing advice, coordination and consultation with a view to improving opportunities for handicapped persons. (Gouvernement du Québec, 2004)"*

From contrasting the above statements of purpose, it is apparent that whilst the OADA explicitly states that accessibility standards are to be developed, implemented and enforced on or before January 1st, 2025, the equivalent Quebec legislation deploys a much softer tone with no definitive deadline for standards to be in place, or without indeed even an assertion that any standards are (or at any point will be) mandatory. The presence of standards and a deadline to adhere to them does not necessarily mean that accessibility for wheelchair users in Ontario is anticipated in this study to be perfect. As the deadline for OADA standards to be in place is by 2025, there are conceivably many buildings or elements of the transport network that are not yet meeting those standards within

Ontario. One of the key examinations within this study is to examine accessibility outcomes for wheelchair users within two different legislative contexts.

STUDY CONTEXT

As the largest metropolitan area in Canada, the Greater Toronto Area, Ontario is home to almost 6.5 million people, of whom 2.7 million live within the City of Toronto (Statistics Canada, 2017). Public transport in the City of Toronto is provided by the Toronto Transit Commission (TTC), which operates a network of subway, streetcar and bus service. Regarding wheelchair access of the TTC network, the TTC operates a fleet of universally accessible buses that are either low-floor or equipped with a ramp. As of 2017, 35 (total 69) stations in the subway network are accessible for customers with physical disabilities, and the remaining 34 stations are planned to be retrofitted with elevators by 2025 (Toronto Transit Commission, 2016). The historic streetcar network is currently transitioning to a fleet of low-floor streetcars, and they anticipate that all streetcar routes will be accessible by 2019 (Toronto Transit Commission, 2017b). To meet the AODA standard for accessibility by 2025, approximately 5% of the TTC's Capital Budget is dedicated to projects that will improve accessibility for customers with disabilities (Toronto Transit Commission, 2016). In addition to the public transport service provided by the TTC, GO Transit operates regional public transport service within the Greater Toronto and Hamilton Area (GTHA). GO Transit consists of a network of commuter trains and a regional bus service. Stations served by the commuter rail service are predominantly wheelchair accessible (56 out of 62 are accessible), and GO Transit operates bus routes with accessible vehicles, however some bus stops are inaccessible and require accommodation for individuals travelling with a wheelchair.

As the second largest metropolitan region in Canada, the Greater Montreal Area, Quebec is home to almost 4 million people, of whom 1.9 million reside on the Island of Montreal (Statistics Canada, 2017). The major employment centers within the Greater Montreal Area are also situated on the Island of Montreal, both in the central business district and in other centers that are accessible by public transport (Manaugh & El-Geneidy, 2011; Shearmur, Coffey, Dube, & Barbonne, 2007). The largest public transport agency in the region is the Société de Transport de Montréal (STM), which operates subway and bus services on the Island of Montréal. Whilst almost all bus services provided by the STM are wheelchair accessible (the exceptions being minibuses and shuttles), at the time of analysis there were 12 wheelchair accessible subway stations equipped with elevators,

from a total network of 68 stations (Société de Transport de Montréal, 2017), but 11 stations were classified as wheelchair accessible in the GTFS data. Between the years 2017 and 2022 the STM plans to invest 213 million dollars for retrofitting subway stations, from a total annual budget of 1.4 billion in 2017. This corresponds to 3% of the annual budget if investments were to be equally distributed across years. The Agence Métropolitaine de Transport (AMT) are responsible for operating commuter rail services which are principally aimed at transporting commuters from distant suburbs to downtown Montreal. Consequently, the service frequency of commuter trains is highest during weekday morning and afternoon peaks, with little service provided on off-peak weekdays and weekends. The AMT network consists of 66 rail stations, of which 10 were wheelchair accessible at the time of analysis (Agence Métropolitaine de Transport, 2017). Table 1 shows a comparison between the two study regions in term of size and universal accessibility adherence when public transport networks are confined to the City of Toronto and Island of Montreal boundaries used within this study. Figure 1 demonstrates a map of the public transport networks in both cities, and displays which subway or commuter rail stations are wheelchair accessible.

Table 1: Summary of demographic characteristics and public transport system accessibility for the study areas

	City of Toronto	**Island of Montreal**
Demographic characteristics		
Population	2.7 million	1.9 million
Number of Jobs	1.1 million	1.3 million
Transport characteristics		
Subway stations	69	64
Of which are accessible:	35	8
GO Transit/AMT stations	21	33
Of which are accessible:	16	8
Wheelchair Accessible Buses	Yes	Yes

Both cities offer a door-to-door paratransit service for individuals with a disability, which is a pre-scheduled service. While this service will remain important in cities to ensure that all residents have access to transport services, it is beneficial to both the individual and the public

transport agency to provide accessible service so individuals in a wheelchair can use the conventional transport network. From an agencies point of view, each trip delivered by paratransit service is extremely costly. Transitioning paratransit customers on to the conventional network is not only more cost-effective for public transport agencies, but is better for individuals who can travel independently and are not isolated in a paratransit vehicle (Currie, 2011).

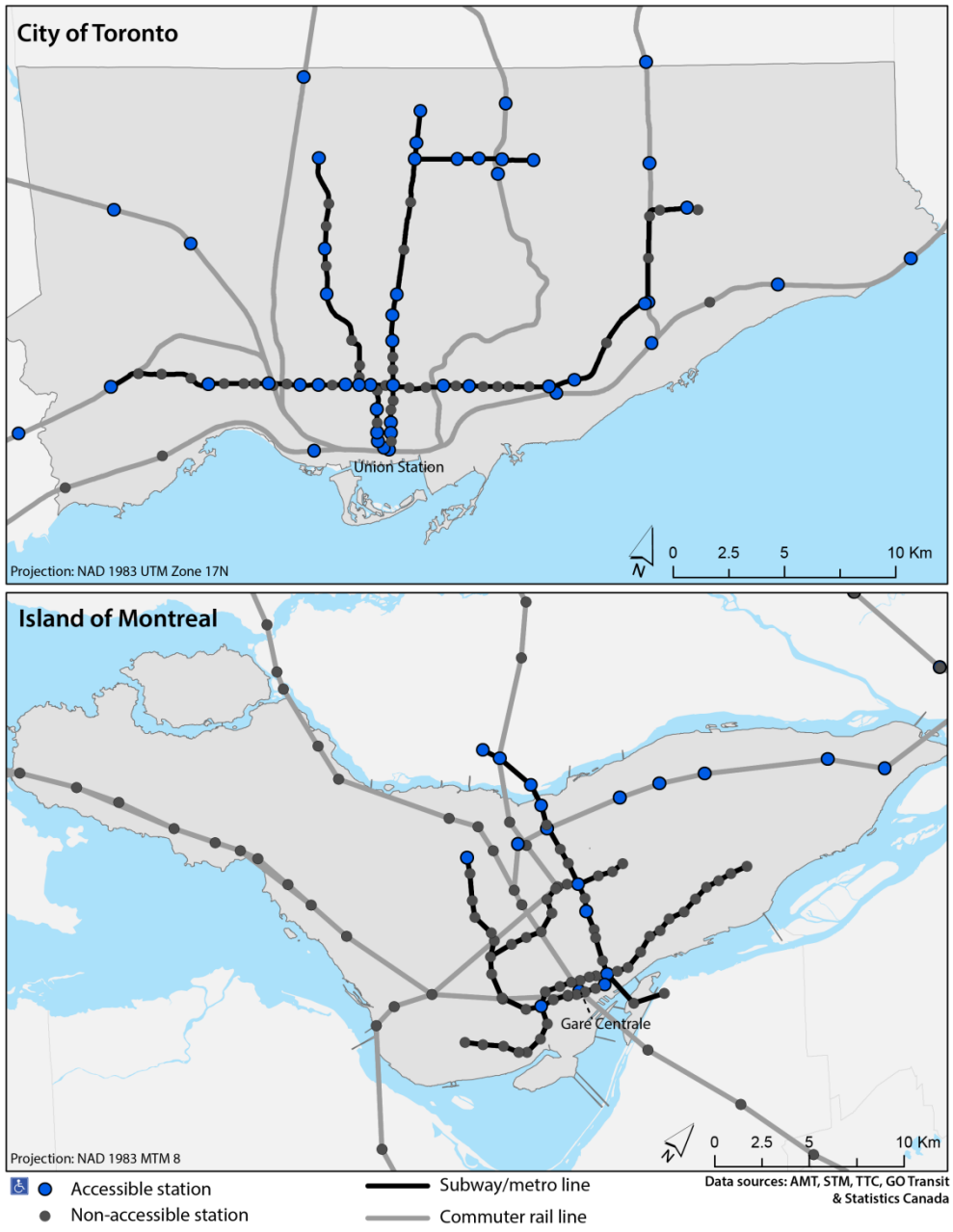

Figure 1: Context maps of the public transport networks in the City of Toronto and the Island of Montreal

DATA

Accessibility analyses require two types of data: travel time and number of jobs. Firstly, General Transit Feed Specification (GTFS) data from Montreal and Toronto was used to calculate travel time between census tracts (CTs) for the general population and for those in wheelchairs. Travel time was calculated at 8:00 am for both study areas (City of Toronto and Island of Montreal) based on data from March 2017 GTFS. Secondly, the number of jobs data was obtained at the CT level from the 2011 National Household Survey commuter flows dataset (Canada, 2011). The final source of data in this analysis consisted of demographic CT information, including median income, unemployment rates, percentage of recent immigrants (immigrated 2006 – 2011) and percentage of tenants spending more than 30% of total income towards shelter costs. These data were used to evaluate levels of job accessibility for wheelchair users residing in socially vulnerable areas. The demographic data were obtained from the 2011 Statistics Canada National Household Survey.

METHODOLOGY

In this article we generate a methodological approach to highlight the gap in accessibility to jobs by public transport in two Canadian cities between people with a physical disability and the rest of the population. Accessibility has been used in the past as a key land use and transport performance measure (Wachs & Kumagai, 1973). It has been also used to measure equity gaps for vulnerable groups, mostly low income population to compare the level of service provided to them (El-Geneidy et al., 2016; Foth et al., 2013; Manaugh & El-Geneidy, 2012). However, accessibility studies have previously commenced with the assumption that the entire public transport network is accessible to all individuals. Generating accessibility to jobs requires obtaining travel time matrices, which were derived from the GTFS data. Two matrices are generated for every region, the first is travel time at 8:00 am between every CT centroid and every other CT centroid in the study areas without consideration of trips for an individual in a wheelchair. These travel times were calculated using the *Add GTFS to a Network Dataset* toolbox in ArcGIS for weekday 8:00 am departure time. Within the GTFS data, public transport providers specify which rail or subway stations are physically accessible for someone traveling in a wheelchair, as well as which trips are operated by a physically accessible vehicle, for example a low-floor bus. Accordingly, using the same *Add GTFS to a Network Dataset* toolbox in ArcGIS for an 8:00 am departure time, we generated a second travel time matrix for each region, yet for people using a wheelchair. In other

words we used two networks in both study areas to generate the travel times, the first for the general population has no restrictions in using any station or bus line, whilst the second is one for the wheelchair users who are restricted to using only the accessible parts of the network.

The calculated routes for public transport trips were based on the shortest travel time, which may not always reflect a trip that a user would take in reality, for reasons such as too many transfers. The travel time of each trip includes walking to the station or stop, in-vehicle travel time and walking to the final destination. An important limitation of this method is that walking distances were not restricted. While there is literature available to guide planners on how long someone is willing to walk to public transport, there is currently no information to guide how far an individual in a wheelchair is willing to travel to reach a bus stop or subway station. Therefore this was not modelled in our study. Furthermore, we did not account for the additional time that may be required for an individual in a wheelchair to travel to and from the transit stop and to transfer either between transit modes or to enter or exit a transit station. Individuals in wheelchairs may experience a delay in their trip as a result of the time needed to navigate a station and to access it due to street-scape issues. For these reasons, we likely overestimated accessibility levels for certain census tracts for people in wheelchairs.

Using the travel time matrices for both wheelchair users and non-wheelchair users, a cumulative opportunity measure of accessibility (number of jobs within 45 minutes) by public transport to jobs at 8:00 am on a weekday (non-holiday) were measured. A threshold of 45 minutes was selected as it represents the average commute time to work by public transport in both regions- Montreal 43 minutes & Toronto 47 minutes as per Statistics Canada (2011). A visual comparison between the levels of accessibility to jobs by public transport at 8:00 am for people using a wheelchair and for those not using one is conducted in the analysis section for the two case studies.

A social deprivation index was also added to the accessibility maps, to help in identifying areas where there are higher proportions of socially vulnerable individuals, and where an individual in a wheelchair will suffer from lower accessibility more significantly than those not using a wheelchair, residing in the same area. Socially vulnerable individuals have been shown to be more transit dependent (Foth et al., 2013), and accordingly, wheelchair users that are socially vulnerable are more likely to suffer from accessibility constraints imposed by the public transport system. In contrast, wheelchair users with lower social vulnerability are more likely to have other options to access job opportunities. In this regard, poor accessibility for wheelchair users is likely to have

greater impacts in areas characterized by a higher proportion of socially vulnerable individuals. To generate a social deprivation index for both regions, median income, unemployment rate, percentage of recent immigrants (2006 – 2011) and percentage of tenants spending more than 30% of total income towards shelter costs in every CT were standardized using a Z-score approach. The standardized scores were then summed with equal weights to create a social deprivation indicator value for each census tract, a method similar to Foth et al. (2013).

The second part of the analysis is where we conducted a direct comparison by calculating the ratio between accessibility with and without a wheelchair by public transport to jobs in both regions. A high ratio (ratio nearer to 100%) indicates a small gap in accessibility, meaning people in a wheelchair are receiving the same level of service as the rest of the population. While a low ratio (less than 60%) indicates a big discrepancy between the accessibility experienced by the two studied populations. Areas with low levels of accessibility in both regions were excluded from the ratio analysis. CTs that fell within the lowest tier of accessibility for non-wheelchair users (using the Jenks natural breaks method) were excluded. The reason for excluding these areas was that the findings can be misleading, as most areas with low levels of job accessibility were found to have very high ratios. The level of public transport service in these low accessibility areas is generally low, with limited to no subway or rail service. Being served only by bus services (which are wheelchair accessible), these areas are characterized by a high ratio. The high ratio could suggest that no improvement is needed in these areas to increase the level of accessibility of individuals in a wheelchair, while in reality the level of service received by both wheelchair and non-wheelchair users is poor.

RESULTS AND ANALYSIS

Commencing with the City of Toronto, Figure 2 shows the accessibility by public transport maps at 8:00 am on a weekday for a person not in a wheelchair and for a person in a wheelchair. For the general population in Toronto (map A), the importance of the subway is evident as accessibility is much higher in the CTs where subway stations are located. Accessibility then decreases as distance from the CBD increases with exceptions around subway stations.

Focusing on accessibility levels for people in a wheelchair in Toronto (map B), a reduction in the number of jobs that can be accessed within 45 minutes is observed. Accessibility is still generally higher along the subway lines for wheelchair users. However, some areas around subway

and commuter lines have low accessibility, as there are significant gaps in wheelchair access of subway stations or commuter rail stations. On average, wheelchair users in the City of Toronto have access to 267,257 jobs, compared to 355,941 jobs accessible to an individual not in a wheelchair. These results suggest that, on average, 75% of the jobs accessible to the general population are accessible to an individual in a wheelchair. Furthermore, 38% of the CTs have high levels of accessibility (more than 500,000 jobs), however when considering wheelchair accessibility, this proportion to 20% of the CTs. These findings indicate that accessibility to jobs is largely reduced when using the wheelchair accessible network in the City of Toronto.

The 20% most socially vulnerable CTs in the City of Toronto experience, on average, greater levels of accessibility (417,762 jobs) relative to the City's average (355,941 jobs). This is also the case for wheelchair accessibility, where 326,825 jobs can be reached using a wheelchair from the most socially vulnerable CTs, compared to 267,257 jobs for all CTs in the City of Toronto. When comparing accessibility for wheelchair users and non-users in socially vulnerable areas in the City of Toronto, a ratio of 78% is observed (75% for the City of Toronto). Accordingly, socially vulnerable areas are experiencing a similar reduction in accessibility to the rest of the City.

The 20% most socially vulnerable CTs in the City of Toronto are split generally into two categories, those that lie centrally within the City and those on the periphery. On average a person in a wheelchair living in a socially vulnerable area in the center of Toronto (CTs within 5 km of the Toronto's major public transport hub Union Station, see Figure 1), will have access to 513,756 jobs within 45 minutes in the a.m. peak compared to 675,102 that a person not in a wheelchair can access at the same time, which corresponds to a ratio of 76%. Meanwhile for socially vulnerable neighborhoods outside the center of Toronto, a person in a wheelchair commuting at 8 a.m. will have access to 314,156 jobs within 45 minutes compared to 257,422 jobs, or 82% of jobs that a person not in a wheelchair can access at the same time. The higher ratio is likely explained by the fact that many socially vulnerable neighborhoods outside the center of the City of Toronto are mainly served by bus services. Since all TTC busses are wheelchair accessible, the difference in accessibility is lower than areas that are served by subway and commuter rail, as well as inaccessible streetcars serving many east-west routes in the central CTs of Toronto. However, a high ratio in these areas is not indicative of high accessibility by wheelchair, since general accessibility is also low.

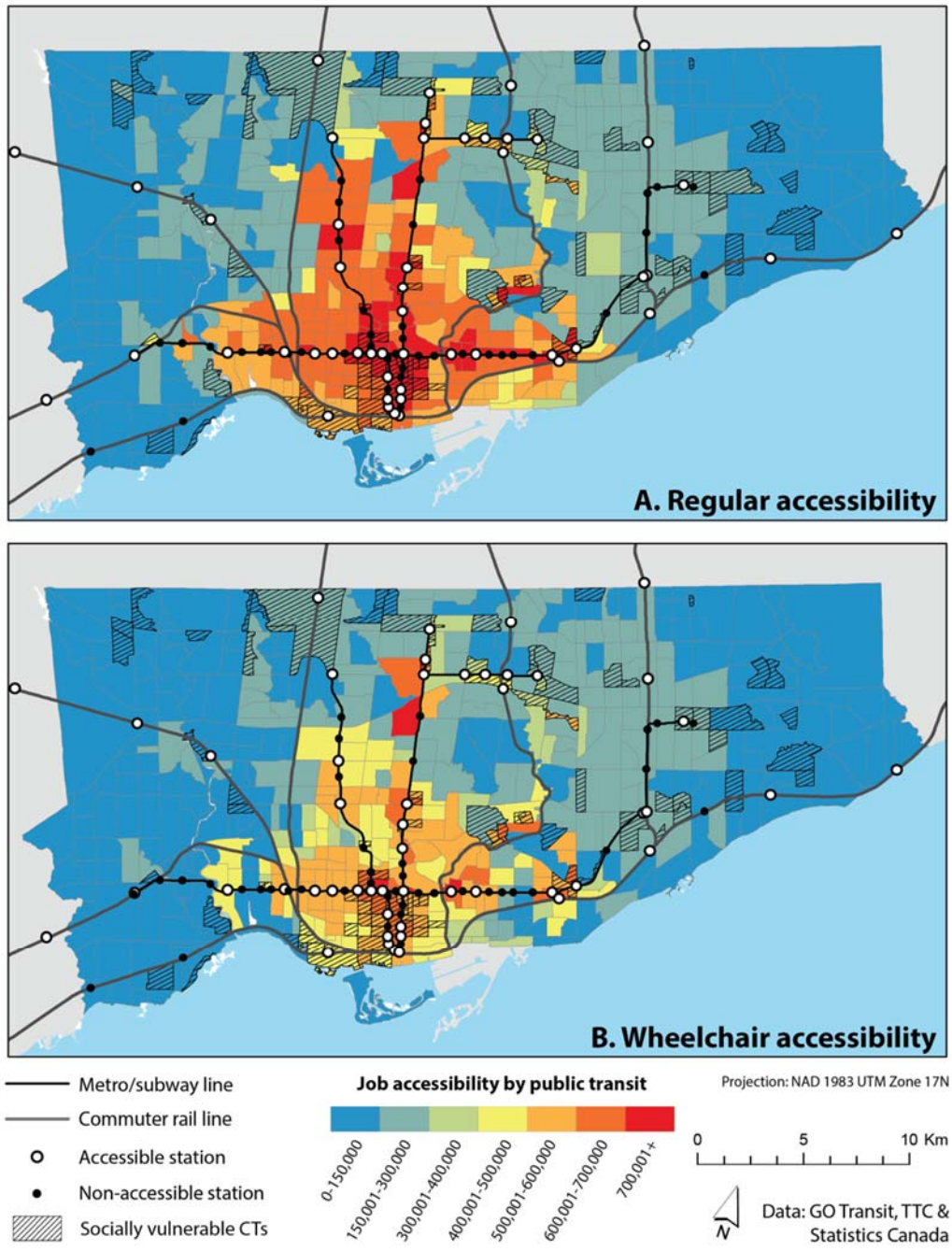

Figure 2: Job accessibility by public transport in the City of Toronto.

As shown in Figure 3, accessibility by public transport in Montreal for the general population portrays a similar narrative to that of Toronto, with accessibility highest within the more central CTs and those closest to the subway and commuter rail lines. The accessibility for a wheelchair user by contrast, demonstrates a startling drop, which is greater than that revealed in

Toronto. On average, wheelchair users on the Island of Montreal have access to 46 % of the jobs that are accessible for an individual not in a wheelchair (190,488 jobs compared to 418,092 jobs). Also, only 3% of the CTs have access to more than 500,000 jobs for an individual in a wheelchair, compared to 50% of the CTs for an individual not in a wheelchair. These discrepancies indicate an important drop in accessibility between individuals in a wheelchair and individuals who are not, which is far more pronounced than in Toronto.

With respect to the 20% most socially vulnerable CTs in Montreal, they also experience, on average, greater levels of accessibility (490,768 jobs) relative to the region's average (418,092 jobs). Wheelchair accessibility is also higher in the most socially vulnerable CTs, where 231,309 jobs can be reached using a wheelchair from the most socially vulnerable CTs, compared to 190,488 jobs for the Island of Montreal. A similar ratio between wheelchair accessibility and non-wheelchair accessibility is observed for socially vulnerable areas (47%) compared to the whole region (46%).

Evaluating these numbers in central and non-central regions of the Island of Montreal, we found that for socially vulnerable areas in the centre of Montreal (CTs within 5 km of Montreal's major public transport hub Gare Centrale, see Figure 1), a person commuting in a wheelchair will have access to 349,280 jobs within 45 minutes in the a.m. peak compared to 667,285 jobs that a person not in a wheelchair can access at the same time, which is approximately 52%. In socially vulnerable neighborhoods in the non-central areas of Montreal, an individual in a wheelchair will have access to 161,915 jobs compared to 386,934 jobs that a person not in a wheelchair can access at the same time, which is a 42% ratio. The higher ratio in central areas can be explained by the proximity to wheelchair-accessible subway stations, while many non-central socially vulnerable CTs are located in proximity to non-wheelchair accessible subway or commuter rail stations.

The findings for the Island of Montreal are not consistent with the findings from Toronto, where the gap in job accessibility for those living in socially vulnerable areas is more pronounced in central areas of the City (76%) compared to non-central areas of Toronto (82%). Non-central socially vulnerable CTs are mainly served by bus service in the City of Toronto, whereas many non-central socially vulnerable CTs on the Island of Montreal are located in proximity to subway service. In this regard, improvements to wheelchair accessibility by public transport for socially vulnerable neighborhoods on the Island of Montreal can be achieved by increasing the number of

wheelchair accessible stations in non-central areas, whereas in the City of Toronto, improvements to the overall level of service in non-central socially vulnerable areas would be needed.

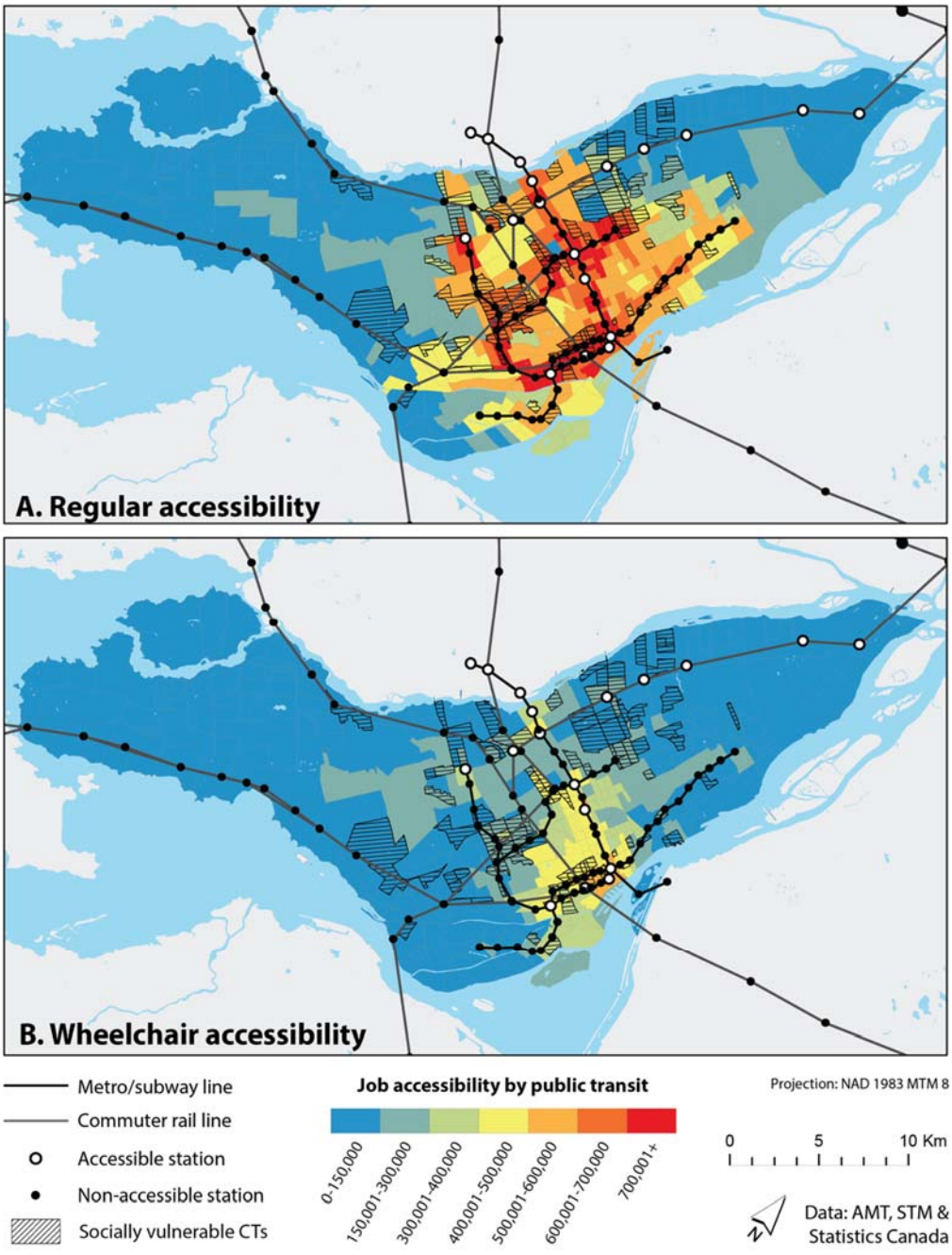

Figure 3: Job accessibility by public transport in Montreal.

Accessibility Ratio

By evaluating accessibility to jobs for individuals in a wheelchair compared to a person not in a wheelchair, large gaps in accessibility were observed for wheelchair users. In this section we want to understand what is most significantly contributing to these gaps, and to highlight areas in need of improvements in universal design of the public transport networks. To do so we focus on areas that have good public transport access for non-wheelchair users, namely around subway stations and commuter rail stations, which are areas where wheelchair users are most greatly excluded from. Accordingly, for the purpose of this analysis, only CTs with medium and high levels of accessibility are considered. The gap in accessibility in areas with poor public transport accessibility is moderate since the overall level of service, which is predominantly provided by buses, requires improvements for the entire population, which is not the focus of the study.

Figure 4 shows the ratio between the levels of accessibility to jobs at 8:00 a.m. for a person in wheelchair compared to a person not using a wheelchair for both case studies, for CTs with medium and high levels of accessibility. The same ratio is also derived for the 20% most socially vulnerable CTs separately.

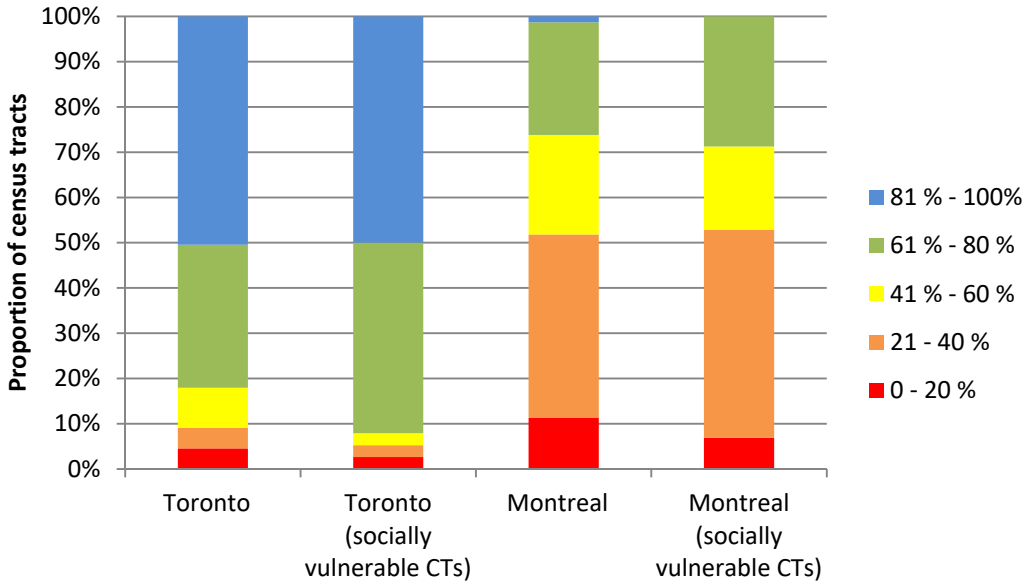

Figure 4: Proportion of census tracts that fall within each accessibility ratio interval in the City of Toronto and the Island of Montreal, for all CTs and socially vulnerable CTs

Commencing with the cities as a whole, in Toronto, around 50 per cent of CTs have an accessibility ratio above 80 per cent, and more than 80 per cent of CTs have a ratio above 60 per cent. In Montreal, only 2 per cent of CTs have a ratio above 80 per cent and almost 30 per cent of

CTs have a ratio over 60 per cent. In contrast, over 50 per cent of Montreal CTs have a ratio below 40%. In the 20 per cent most socially vulnerable CTs in Toronto, we can see that these neighborhoods are marginally better off, where a lower proportion of them have a ratio below 60 per cent compared to the rest of the region. The proportion of socially vulnerable CTs with a ratio below 20 per cent is lower in the most socially vulnerable Montreal CTs, but no socially vulnerable CT in Montreal has a ratio above 80 per cent.

Overall, these results further highlight that the Island of Montreal is characterized by greater gaps in wheelchair accessibility. Nonetheless, in both the City of Toronto and the Island of Montreal, no census tracts characterized by medium and high levels of accessibility have a ratio of 100%. Since any gap below 100% should be resolved to ensure equal access to jobs for wheelchair and non-wheelchair users, these findings highlight that all areas need improvements in wheelchair accessibility, especially through the retrofitting of subway and commuter rail systems in Montreal and Toronto as will be discussed below. Figure 5 highlights the differences in these ratios spatially. Again, in these maps we only display accessibility ratios of CTs with medium and high levels of accessibility to focus our analysis on the gap in accessibility between public transport users in a wheelchair and those not using a wheelchair. These maps can be used by public transport planners and city officials, to identify priority areas for improving public transport accessibility for wheelchair users.

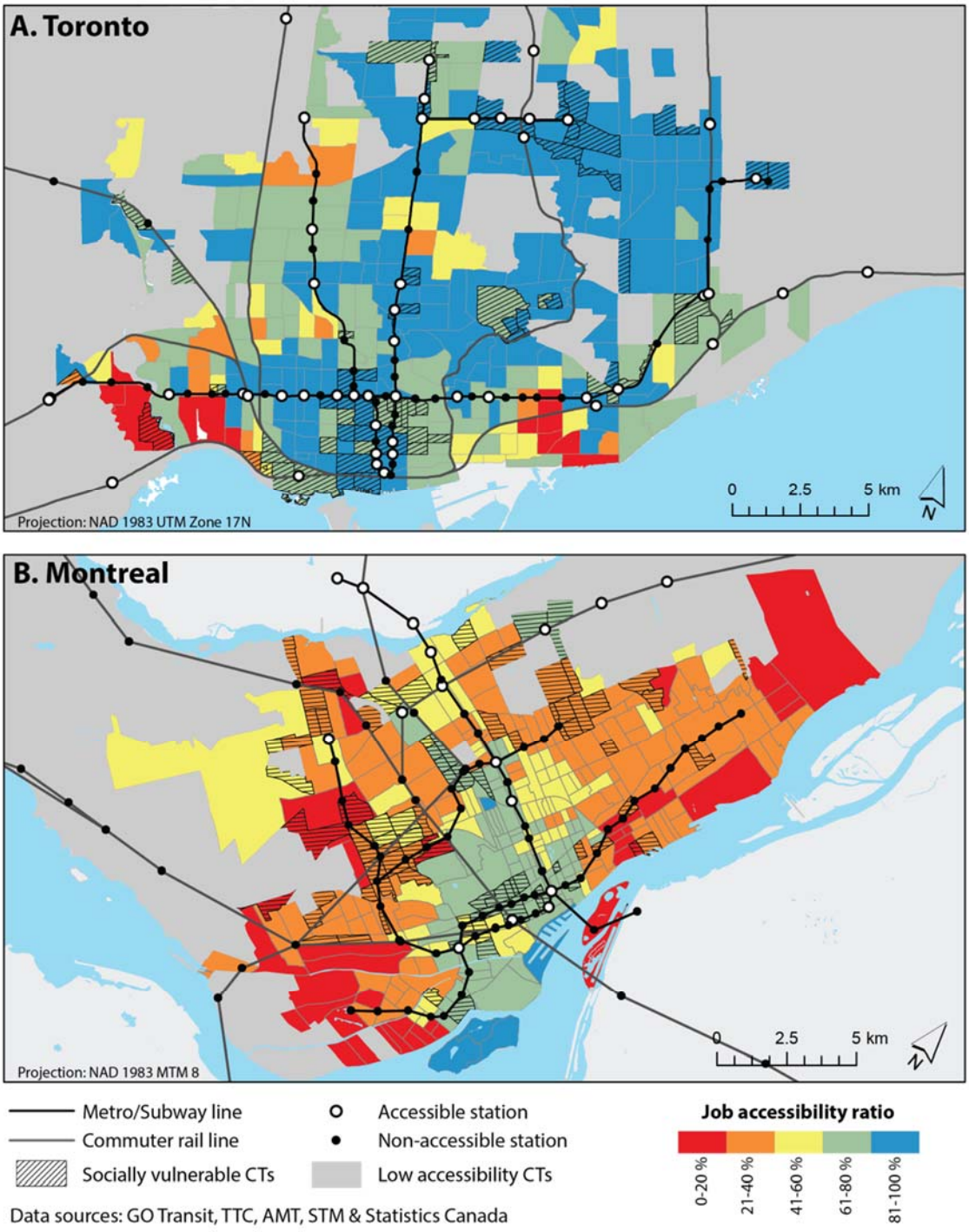

Figure 5: Accessibility ratio

When comparing the two public transport networks, and accessibility ratios, the effect of large gaps in accessible subway stations and commuter rail stations is evident. Within Toronto, CTs with the lowest ratios (less than 40 %) are mainly located around non-accessible stations as excluding these stations from the network to run the wheelchair accessible model would have

unsurprisingly resulted in a significant reduction in subsequent accessibility. There are two regions in Toronto, where the accessibility ratio is lowest (under 20%). These areas are located in CTs located just south of the Bloor-Danforth line, which is the major east-west subway line. Low ratios in job accessibility can be largely attributed to gaps in subway station accessibility, where individuals living in proximity to these stations must either take a bus to a nearby wheelchair accessible station, or consider other alternatives to reach their desired destinations. These low ratios can be addressed by retrofitting of the subway stations on the Bloor-Danforth line in these areas.

Within Montreal, very low ratios (under 20%) are largely found in areas surrounding the non-central portions of the Green subway line, which extends from the Southwest to the Northeast of the region, through Gare Centrale. This is again unsurprising as the entire Green line consists of only two wheelchair accessible stations that are interchange stations, which results in a dramatic reduction in accessibility for wheelchair users in contrast to the general population. High and medium ratios (above 40%) are mainly located around stations that are accessible to wheelchair users on the north-eastern portion of the Orange subway Line (the U-shaped subway line that crosses to the North Shore of Montreal) and downtown, where there is the greatest concentration of wheelchair accessible stations and the only wheelchair accessible commuter rail line serves portions of this corridor. The spatial concentration of accessible subway stations and commuter rail stations is evident on the map, and results in an extremely unequal distribution of job accessibility for wheelchair users, across the Island of Montreal. Accordingly, these gaps in subway station accessibility in Montreal need to be addressed, both in the long term by planning the retrofitting of stations in areas with large gaps, as well as in the short term by increasing alternatives for these individuals, such as feeder bus service to accessible subway stations.

Furthermore, the 20% most socially vulnerable CTs are displayed on the maps, in order to identify areas where there are high proportions of socially vulnerable individuals, who are likely to be negatively affected by low accessibility to jobs by public transport. Accordingly, from a social equity perspective, socially vulnerable CTs should receive special attention for improvements in universal design of the public transport systems, especially those currently characterized by a low ratio. In the City of Toronto, a few socially vulnerable CTs are experiencing very low accessibility ratios on the western portion Bloor-Danforth line. On the Island of Montreal, several pockets of socially vulnerable CTs are experiencing low ratios, namely around the western portion of the Orange subway line, and on the eastern areas of the Island. By displaying accessibility ratios and

socially vulnerable CTs, these maps highlight areas which are in need of improvements, both from a social and spatial perspective.

DISCUSSION AND CONCLUSION

Developing public transport service that follows universal design principles is an important target for public transport agencies to ensure that the built environment is not disabling individuals in a wheelchair. In this study, we evaluated public transport networks in two Canadian cities, Montreal and Toronto, where both cities are retrofitting their networks to ensure that all individuals can use the public transport system. The objective of this study was to generate a methodology using accessibility measures to jobs to identify the gaps in accessibility by public transport to jobs for wheelchair users compared to non-wheelchair users. Using GTFS data that provide details regarding whether public transport stations are accessible for individuals in a wheelchair and whether trips are operated with an accessible vehicle, we calculated the number of jobs that can be reached within 45 minutes of travel by public transport for an individual in a wheelchair and compared this number to the total number of accessible jobs for a person not in a wheelchair. The results of this study contribute to the accessibility literature by presenting a new method of evaluating the performance of the transport and land use system that considers how well the public transport network is able to connect wheelchair users in a region to employment opportunities. The methods of this study can be replicated in other contexts where physical access information is provided by transit agencies within GTFS data as well as demonstrating how transit agencies can apply such data to generate accessibility measures that are sensitive to physical access. In a robust quantitative culture, measuring the level of transit (in)accessibility for these disadvantaged groups will have important impacts for bringing attention to how significant this issue is. The findings demonstrate how large the gap in accessibility to jobs is between wheelchair users and the general population currently is, which points to the need for interventions to increase access for individuals with physical disabilities. Furthermore, we identified areas in both cities that have high proportions of socially vulnerable individuals, to highlight locations in the network that should be identified as priority locations for intervention. Access to employment opportunities through public transport in socially vulnerable neighborhoods is particularly critical for the well-being of physically disabled individuals, who are more likely to lack alternative means for mobility. While this study focused on public transport trips for individuals in a wheelchair, findings from this research can be of value

for many individuals beyond those in a wheelchair, for example older adults, individuals traveling with a stroller, or travelers with heavy bags or luggage.

In the City of Toronto, there are clear goals to retrofit all inaccessible subway stations by 2025, in accordance with the AODA legislation. As of 2016, approximately half of Toronto's subway stations were wheelchair accessible, and to this effect on average, wheelchair users in Toronto have access to 75% of jobs that are accessible to users without a disability. Accordingly, job accessibility for individuals traveling in a wheelchair is lower than regular accessibility, which is particularly evident around inaccessible subway stations and areas in the downtown core which are predominantly served by inaccessible streetcars. The STM's scheduled accessibility plan aims to have 41 subway stations accessible by 2025, which is phase 1 of their accessibility plan. However 11 subway stations were accessible at the time of this analysis and as a result has revealed more severe disparities in accessibility levels. Individuals traveling in a wheelchair in Montreal have access to only 46% of the jobs accessible to other users.

A major difference in the wheelchair accessibility ratio between these two cities can be explained by large spatial gaps in subway and commuter rail station access in Montreal. Accessible stations can only be found on one line of both the subway and commuter rail network, and as a result, there are large gaps in the region where individuals in a wheelchair cannot access the subway system. It is evident by the results of the ratio of accessibility measures, that subway access and access to rail service is imperative to job accessibility, because of the efficient and frequent service offered by rail.

The process of retrofitting subway stations with elevators to ensure universal design principles are met is time consuming due to the construction and financial challenges associated with adding elevators in older structures. However, in the shorter term, operating wheelchair accessible feeder bus service to stations with elevators can help in reducing the noticeable gap in accessibility. In order to make this policy more feasible, and to reduce spatial gaps in network accessibility, it is recommended that subway station upgrades are prioritized at locations where there are no nearby accessible stations. Such an approach will likely increase the number of destinations accessible by public transport for individuals in a wheelchair.

Public transport agencies are facing rising costs of delivering paratransit service for individuals with physical or cognitive disabilities, particularly with the aging population. Transitioning individuals in a wheelchair who are otherwise able to use the conventional system if

physical barriers are removed, is a more feasible and cost-effective strategy for public transport agencies (Rosenbloom, 2007). In select cities, for example Toronto, paratransit services are moving towards a Family of Services model, which aims for increased integration of paratransit service with the conventional network, for increased independence and freedom for customers, as well as the goal of greater spontaneity of trips for these individuals (Toronto Transit Commission, 2017a). However, the effectiveness of this policy would be hindered in areas of a city with large gaps of accessible stations in the subway system.

We acknowledge the several limitations in this study which when considered, raise further questions regarding the true level of accessibility for wheelchair users. One limitation relates to the nature of the jobs. It is of course not possible that anyone would be a suitable candidate for all jobs that they could reach within the threshold. Studies such as ours, risk being misinterpreted or used to pursue a narrative that disparages the unemployed, regardless of their disability status. The structural nature of employment or underemployment of course means that many factors such as job sector, seniority, and specifications of any role have to be considered by individuals when determining what pool of jobs are available to them. This study does not distinguish jobs by sector or any other criteria that would reflect the employment climate for an individual in reality. It instead broadly measures the total number of jobs available to society as a whole. Nevertheless, job accessibility is a general indicator of the quality of public transport in relation to land use activities.

Another related limitation is that we do not account for the numbers of individuals that have access to every job, by car or public transport. In other words, the competition effect is not included in this study. While such measure is relevant to assess the effect of accessibility on employment outcomes or mode choice, the competition component falls outside the scope of this paper, where the aim is to assess the geographical access to jobs provided by the land use and transport systems to individuals with a disability, relative to the general population. Including job competition would yield similar results, since from a geographical perspective, the competition for individuals with a disability and the general population is the same.

It would be unwise to claim that the presence of provincial legislative standards is the sole reason for relatively better wheelchair accessibility in Toronto when compared with Montreal. The nature of how infrastructure was originally designed and constructed many years ago in both cities plays a large role in determining whether buildings have to be retrofitted. Public transport agencies can conceivably attain the title of a universally accessible network at considerably less cost where

their original infrastructure was either intentionally or unintentionally constructed in a wheelchair accessible manner. As we see more definitive ambitions for standards in Ontario accessibility legislation, we also see greater accessibility of wheelchair users in Toronto, although we have demonstrated that some areas remain poorly served by accessible public transport service. Montreal by contrast, has substantial network gaps for wheelchair users, given that one entire subway line has only two accessible stations. Whilst STM has developed their own ambitions to make the network universally accessible, there is no existing provincial legislation that enforces this to be achieved by a given time. We cannot speculate at this stage whether a future federal disability act will require and enforce all provinces in Canada to adopt equivalent standards to the AODA by a given date or whether such an act would merely suggest and recommend measures, as per the current Quebec legislation. Were it to aspire for the same impact as the United States ADA, then it would certainly be worthwhile returning to a similar study in future to evaluate the impact on accessibility for wheelchair users that such legislation provides.

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References

Agence Métropolitaine de Transport. (2017). Accessibility on the Mascouche line. Retrieved from https://rtm.quebec/en/accessibility/mascouche-line

BC Stats. (2009). *Labour Market Outcomes of Persons with Disabilities in British Columbia*. Retrieved from Victoria, B.C.:

Ben-Akiva, M., & Lerman, S. (1979). Disaggregate travel and mobility choice models and measures of accessibility. In D. Hensher & P. Stopher (Eds.), *Behavioural travel modelling* (pp. 654-679). London: Croom-Helm.

Benoit, C., Jansson, M., Jansenberger, M., & Phillips, R. (2012). Disability stigmatization as a barrier to employment equity for legally-blind Canadians. *Disability & Society, 28*(7), 970-983.

Bocarejo, J., & Oviedo, D. (2012). Transport accessibility and social inequities: A tool for identification of mobility needs and evaluation of transport investments. *Journal of Transport Geography, 24*, 142-154.

Bromley, R. D. F., Matthews, D. L., & Thomas, C. J. (2007). City Centre Accessibility for Wheelchair Users: The Consumer Perspective and the Planning Implications. *Cities, 24*(3), 229-241.

Canada, S. (2011). Profile of Census Tracts.

Currie, G. (2011). *New Perspectives and Methods in Transport and Social Exclusion Research*. Bingley: Emerald

El-Geneidy, A., & Levinson, D. (2006). *Access to destinations: Development of accessibility measures*. Retrieved from Minneapolis, MN:

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., & Loong, C. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice, 91*, 302 - 316.

Evcil, A. N. (2009). Wheelchair Accessibility to Public Buildings in Istanbul. *Disability and Rehabilitation: Assistive Technology, 4*(2), 76 - 85.

Foth, N., Manaugh, K., & El-Geneidy, A. (2013). Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996-2006. *Journal of Transport Geography, 29*, 1-10. doi:10.1016/j.jtrangeo.2012.12.008

Geurs, K., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography, 12*, 127-140.

Golub, A., & Martens, K. (2014). Using principles of justice to assess the modal equity of regional transportation plans. *Journal of Transport Geography, 41*, 10-20.

Gouvernement du Québec. (2004). *Act to secure handicapped persons in the excercise of their rights with a view to achieving social, school and workplace integration*. Retrieved from

Government of Ontario. (2005). *Accessibility for Ontarians with Disabilities Act, 2005*. Retrieved from

Guzman, L., Oviedo, D., & Rivera, C. (2017). Assessing equity in transport accessibility to work and study: The Bogotá region. *Journal of Transport Geography, 58*, 236-246.

Hagg, M., & El-Geneidy, A. (2010). *Making the Montreal indoor city accessible to people with disabilities.* Paper presented at the 89th Transportation Research Board Annual Meeting, Washington D.C., USA.

Handy, S. (1994). Regional versus local accessibility: Implications for non-work travel. *Transportation Research Record*(1400), 58-66.

Hansen, W. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners, 25*(2), 73-76.

Imrie, R., & Kumar, M. (1998). Focusing on Disability and Access in the Built Environment. *Disability & Society, 13*(3), 357-374.

Kitchen, R., & Law, R. (2001). The Socio-Spatial Construction of (In)accessible Public Toilets. *Urban Studies, 38*(2001), 287-298.

Korsu, E., & Wenglenski, S. (2010). Job accessibility, residential segregation, and risk of long-term unemployment in the Paris region. *Urban Studies, 47*(11), 2279 - 2324.

Lillie, E., Alvarado, B., & Stuart, H. (2013). Unemployment among Canadians with physical and a co-morbid mental disability: An examination of the 2006 Participation and Activity Limitation Survey (PALS). *Disability and Health Journal, 6*(4), 352-360.

Manaugh, K., Badami, M., & El-Geneidy, A. (2015). Integrating social equity into urban transportation planning: A review of metropolitan transportation plans in North America. *Transport Policy, 37*, 167-176.

Manaugh, K., & El-Geneidy, A. (2011). Validating walkability indices: How do different households respond to walkability of their neighbourhood? *Transportation Research Part D: Transport and Environment, 16*(4), 309-315.

Manaugh, K., & El-Geneidy, A. (2012). Who benefits from new transportation infrastructure? Using accessibility measures to evaluate social equity in public transport provision. In K. Geurs, K. Krizek, & A. Reggiani (Eds.), *Accessibility and Transport Planning: Challenges for Europe and North America* (pp. 211-227). London, UK: Edward Elgar.

Martens, K. (2012). Justice in transport as justice in accessibility: Applying Walzer's 'Spheres of Justice' to the transport sector. *Transportation, 39*(6), 1035-1053. doi:10.1007/s11116-012-9388-7

Martens, K. (2017). *Transport Justice: Designing Fair Transportation Systems*. New York, N.Y.: Routledge.

Matas, A., Raymond, J., & Roig, J. (2010). Job accessibility and female employment probability: The cases of Barcelona and Madrid. *Urban Studies*.

McMillen, B. (2001). *Policies, Resources and Programs for Providing Accessible Pedestrian Systems in the USA*. Paper presented at the Walk21 3rd International Conference: Steps towards livable cities, San Sebastian, Spain. http://www.walk21.com/papers/San%20Sebastian%2002%20McMillen%20Policies%20resrouces%20and%20programmes%20.pdf

Owen, A., & Levinson, D. (2014). Retrieved from Minneapolis, MN:

Pucher, J., & Renne, J. L. (2003). Socioeconomics of urban travel: Evidence from the 2001 NHTS. *Transportation Quarterly, 57*(3), 49-77.

Rosenbloom, D. (2007). Transportation Patterns and Problems of People with Disabilities. In M. Field & A. Jette (Eds.), *The Future of Disability in America*. Washington, D.C.: National Academies Press.

Sanchez, T. W., Shen, Q., & Peng, Z.-R. (2004). Transit mobility, jobs access and low-income labour participation in US metropolitan areas. *Urban Studies, 41*(7), 1313-1331. doi:10.1080/0042098042000214815

Sari, F. (2015). Public transit and labor market outcomes: Analysis of the connections in the French agglomeration of Bordeaux. *Transportation research part A: policy and practice, 78*, 231-251.

Shearmur, R., Coffey, W., Dube, C., & Barbonne, R. (2007). Intrametropolitan employment structure: Polycentricity, scatteration, dispersal and chaos in Toronto, Montreal and

Vancouver, 1996-2001. *Urban Studies, 44*(9), 1713-1738. doi:10.1080/00420980701426640

Société de Transport de Montréal. (2017). Using public transit in a wheelchair. Retrieved from http://www.stm.info/en/access/using-public-transit-wheelchair

Statistics Canada. (2011). *2011 National Household Survey: Data tables*. Retrieved from: http://www12.statcan.gc.ca/nhs-enm/2011/dp-pd/dt-td/Ap-eng.cfm?LANG=E&APATH=7&DETAIL=0&DIM=0&FL=C&FREE=0&GC=0&GID=0&GK=0&GRP=0&PID=107643&PRID=0&PTYPE=105277&S=0&SHOWALL=0&SUB=0&Temporal=2013&THEME=94&VID=0&VNAMEE=Commuting%20duration%20(6)&VNAMEF=Dur%C3%A9e%20du%20trajet%20domicile-lieu%20de%20travail%20(6)

Statistics Canada. (2016). Canadian Survey on Disability, 2012: Mobility disabilities among Canadians aged 15 years and older, 2012. Retrieved from http://www.statcan.gc.ca/pub/89-654-x/89-654-x2016005-eng.htm

Statistics Canada. (2017). Population and Dwelling Counts, for Canada, Provinces and Territories, Census Metropolitan Areas and Census Agglomerations, 2016 Census. Retrieved from http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/dt-td/index-eng.cfm

Toronto Transit Commission. (2016). Accessible Service Transit Plan. Retrieved from http://www.ttc.ca/TTC_Accessibility/Accessible_Transit_Services_Plan/Accessible_Service_Transit_Plan_2016/index.jsp

Toronto Transit Commission. (2017a). Family of Service Pilot Program. Retrieved from http://www.ttc.ca/WheelTrans/Family_Services_program/index.jsp

Toronto Transit Commission. (2017b). Riding the Streetcar. Retrieved from http://www.ttc.ca/TTC_Accessibility/Easier_access_on_the_TTC/Riding_the_streetcar.jsp

Tyndall, J. (2015). Waiting for the R train: Public transportation and employment}. *Urban Studies, 54*(2), 520 - 537.

Vickerman, R. (1974). Accessibility, attraction, and potential: A review of some concepts and their use in determining mobility. *Environment and Planning A, 6*, 675-691.

Wachs, M., & Kumagai, T. (1973). Physical accessibility as a social indicator. *Socioeconomic Planning Science, 7*, 327-456.