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Operationalizing accessibility thresholds: Identifying perceived minimum and sufficient accessibility in Canada

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ABSTRACT

As accessibility becomes integral to transport planning, it is important to identify operational thresholds for evaluating access to essential destinations. Motivated by the operationalization gap between theory and planning practice, we develop a methodology to identify two levels of accessibility thresholds: Perceived Minimum Accessibility (PMA), representing basic access to essential destinations, and Perceived Sufficient Accessibility (PSA), representing convenient access. Using data from the nationwide Canadian Mobility Survey ($N = 15{,}960$), we analyse the relationship between perceived accessibility to grocery stores, healthcare, and leisure destinations by walking and public transit and the participants' corresponding calculated accessibility by public transit. We apply binned log-linear regressions combined with a quartile-based approach to identify region-specific PMA and PSA thresholds. We then assess threshold coverage for the general and low-income populations and map their spatial distribution across income groups. Finally, we examine how these thresholds relate to travel behaviour by estimating weekly walking and public transit mode share using region-specific weighted linear regressions and marginal effects analysis. Our findings reveal substantial regional variation. Large regions achieve broad coverage at the PMA level but require significant improvements to reach PSA levels. Mid-sized and smaller regions often struggle to meet PMA for most of their population, and PSA levels remain largely unattainable under current conditions. PMA levels yield only modest gains in sustainable mode share, whereas PSA levels are associated with considerably higher levels of walking and public transit use. By developing perception-based accessibility thresholds, this study provides a practical framework to support more equitable and sustainable transport and land-use planning.

1. Introduction

Integrating accessibility, the ability of individuals to reach destinations, in transport planning has become a central concern in recent years (El-Geneidy and Levinson, 2022; Ryan and Martens, 2023; Siddiq and Taylor, 2021), with the aim of avoiding social exclusion and promoting wellbeing (Lucas, 2012). In the transport planning literature, frameworks such as *sufficientarianism* and the *capability approach* have been proposed to evaluate levels of accessibility provision (Karner et al., 2024; Lucas et al., 2016; Martens, 2016b; Miller, 2018). ***Sufficientarianism*** holds that planning should prioritize raising accessibility above a certain threshold for all residents beyond which it does not matter how much more others can have (Golub and Martens, 2014; Grengs, 2010; Karner et al., 2024), while the *capability approach* evaluates accessibility in terms of whether individuals have freedom to reach the destinations necessary for social participation (Beyazit, 2011; Nahmias-Biran and Shiftan, 2020; Pereira et al., 2017; Vecchio and Martens, 2021). These frameworks establish a normative case for accessibility standards: that some level of access constitutes a floor below which planning has a responsibility to intervene. However, neither framework specifies how such thresholds should be empirically identified in planning practice. While some studies attempted setting participation-based thresholds (Martens, 2016a; Pot et al., 2024), car-accessibility-based benchmark standards (van der Veen et al., 2020), or examining transit-desert spatial distribution (Aman and Smith-Colin, 2020; Guo and Brakewood, 2024; Jiao and Dillivan, 2013), they offer limited empirical guidance for determining what constitutes “enough” accessibility in practice.

Motivated by this operationalization gap, we propose an empirical approach to identifying accessibility planning descriptive benchmarks grounded in perceived experience. While much of the transport equity literature calls for accessibility standards (Karner et al., 2024; Pereira et al., 2017), it does not distinguish between minimum and sufficient

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accessibility. We argue that they should not be treated synonymously. A minimum threshold may prevent some transport disadvantage, yet it may remain too low to support wellbeing (Hananel and Berechman, 2016; Lucas, 2012). Planning practice should distinguish between a minimum accessibility threshold that allows basic access to essential destinations and a sufficient accessibility threshold that ensures convenient access to these destinations.

Identifying these thresholds requires both a calculated measure of accessibility and a perception-based one. Calculated accessibility quantifies individuals' ability to reach destinations given land use and transport system configurations (Dalvi and Martin, 1976; Handy, 1992, 2023; Hansen, 1959; Levinson and Wu, 2020) and has been extensively used to study travel behaviour, economic development, transport equity, and transport policies and plans (Foth et al., 2013; Golub and Martens, 2014; He, 2020; Luo et al., 2023; Manaugh et al., 2015; Moniruzzaman and Páez, 2012; Owen and Levinson, 2015; Ton et al., 2020). Calculated accessibility alone may not reflect how individuals experience their opportunities to reach essential destinations given their personal characteristics, needs, and constraints; and ignoring perceptions of accessibility could misrepresent the lived experience (Negm et al., 2025a; Pot, 2025). Therefore, we argue that perceptions of accessibility should play a central role in defining these thresholds. In this paper, we use the perceived accessibility definition by Negm et al. (2025a) as "*the perception of how easily one can access their desired destinations using a (range of) specific mode(s).*" While accessibility by public transit is the primary focus of this paper at the regional scale, we combine perceived accessibility by public transit (PT) and walking to capture the full range of sustainable access. This approach reflects the role of destination proximity in shaping sustainable mode viability: where destinations are nearby, walking may substitute for PT, and lower perceived transit accessibility does not necessarily indicate limited sustainable access.

In that light, we define Perceived Minimum Accessibility (PMA) and Perceived Sufficient Accessibility (PSA) as the calculated accessibility levels at which more than 50% and at least 75% of residents, respectively, perceive that they can easily reach their desired essential destinations by PT and/or walking. For PMA, we adopt the median threshold as a majority criterion, representing the accessibility level at which at least half of residents perceive basic access to essential destinations. For PSA, we adopt the third quartile threshold to represent a strong majority of participants, reflecting broad consensus without requiring unanimity. This quartile-based approach provides a transparent and distribution-sensitive method for identifying empirically grounded planning thresholds.

This research provides a new methodology for identifying PMA and PSA thresholds in Canadian regions based on calculated and perceived accessibility levels and examine their influence on travel behaviour. To achieve this goal, we use data from a nationwide Canadian transport survey ($N = 15{,}960$), which includes measures of perceived accessibility, travel behaviour, travel identity and attitudes, and socioeconomic characteristics. These data are paired with region-specific cumulative opportunities accessibility measures. We use binned log-linear regression analysis to identify region-based PMA and PSA. We then examine their impact on weekly travel behaviour using weighted linear regression models followed by a marginal effects analysis. This paper is structured as follows: Section 2 presents the literature review, covering efforts to set accessibility standards, the role of calculated and perceived accessibility, and the operationalization gap that motivates this study. Section 3 presents the data used in the analysis. Given the methodological focus of this paper, Section 4 presents the analytical framework and empirical results jointly. Finally, Section 5 presents the conclusion of the study.

2. Literature review

2.1. Setting standards of accessibility

In recent years, there have been efforts to position transport provision within the framework for equitable transport planning such as *sufficientarianism* and the *capability approach* (Karner et al., 2024; Martens, 2016b; Nahmias-Biran et al., 2017; Pereira et al., 2017; van Wee and Mouter, 2021). While these frameworks offer guidance on what could constitute a just transport system, their application in empirical research often relies on simplified quantitative tools and their implementation in planning practice is still challenging (Ryan and Martens, 2023).

2.1.1. Sufficient accessibility

Sufficientarianism provides a useful conceptual starting point to defining what constitutes a sufficient level of accessibility in the transport literature. It suggests that each individual should have access to at a baseline level of transport resources, beyond which, it does not matter how much more others can have (Meyer and Roser, 2006). In transport, this concept guides the research on transport/accessibility poverty and disadvantage, where one would not be able to access essential activities because of the lack of a baseline level of transport resources, services, safety, and accessibility. This poverty can stem from various factors, including the absence of private vehicles, inadequate PT services, financial constraints, physical barriers in vehicles and spaces, belonging to specific socioeconomic or marginalized groups, or a combination of these elements (Golub and Martens, 2014; Grengs, 2010; Karner et al., 2024). However, translating this concept into a concrete and operational threshold has proven difficult.

Martens (2016a) proposed setting the threshold at the point where activity participation benefits reach a meaningful level, to be determined through democratic deliberation, but empirical attempts to link sufficient accessibility to activity participation benefits have found little to no association between the two, revealing difficulties in quantifying sufficient accessibility (Pot et al., 2024). van der Veen et al. (2020) used average calculated accessibility by car in Rotterdam to define sufficiency thresholds and applied these thresholds to assess accessibility levels across other transport modes, highlighting spatial differences in the fairness of transport provision. This approach uses car accessibility as a reference benchmark for evaluating accessibility sufficiency across the city, constraining other modes to the spatial reach of driving. However, accessibility is inherently mode-specific and should be evaluated based on the ease and extent of destinations reachable by each mode, rather than in comparison to car accessibility.

2.1.2. Gaps in transport provision

Other methods focus on identifying the gaps and needs in demand (Currie, 2004; Karner et al., 2024). Areas characterized by accessibility poverty by PT are often referred to as transit or service "deserts" (Aman and Smith-Colin, 2020; Guo and Brakewood, 2024; Jiao and Dillivan, 2013). Identifying these areas is based on the definition of the potentially disadvantaged populations that would rely on transit, referred to as transit-dependents, whose accessibility needs to essential services are unmet (Jiao and Dillivan, 2013). Social indicators are typically used to identify such disadvantaged groups, concentrating on specific socioeconomic variables such as unemployment rates, household income, the proportion of ethnic minorities, or particular age demographics such as the elderly (Church et al., 2000; Currie et al., 2010; Dodson et al., 2006; Foth et al., 2013). These indicators are used to identify socially disadvantaged areas examined in relation to accessibility outcomes of different transport systems.

2.1.3. Accessibility as a capability

The Capability Approach (Nussbaum, 2009; Sen, 2008), has been recently given attention as a framework that accounts for heterogeneity in individuals' experiences with transport, useful for integrating social equity into transport policy-making and evaluation (Beyazit, 2011; Nahmias-Biran and Shiftan, 2020; Pereira et al., 2017; Vecchio and Martens, 2021). From this perspective, Pereira et al. (2017) argue that accessibility can be understood as a capability that allows for the freedom to reach valued destinations and that transport policy should guarantee minimum standards of accessibility to essential destinations, prioritize disadvantaged groups, and avoid sacrificing individuals' basic rights in the pursuit of aggregate accessibility gains. While this framework introduces complexity, it provides a useful lens for understanding why individuals with different backgrounds may experience and use the transport system differently, a consideration that motivates the need for both calculated and perceived dimensions when setting accessibility thresholds.

2.2. Calculated and perceived accessibility

Both calculated and perceived measures of accessibility should be considered when setting standards for accessibility, as they complement each other. Place-based calculated measures quantify the potential of a location to provide access to spatially distributed opportunities as a function of travel time, departure time, travel mode, and destination quantity (Dalvi and Martin, 1976; Geurs and Van Wee, 2004; Handy, 1992; Hansen, 1959; Levinson and Wu, 2020). While valuable as scalable planning tools, their aggregate nature treats all persons within a spatial unit as equally positioned to take advantage of available opportunities. For example, the place-based cumulative opportunity measures count the number of opportunities reachable from an origin point within a given travel time threshold by a person using a certain mode, overlooking individual space-time constraints. While person-based measures address this limitation by explicitly modelling individual constraints using time-geography frameworks (Miller, 2007), they require detailed activity diaries or time-use data that are rarely available at the regional scale and are difficult to aggregate into the kind of population-level planning benchmarks this study aims to establish.

Perceived accessibility addresses the individual gap in a complementary way to calculated place-based accessibility, capturing how people subjectively assess their ability to reach desired destinations, conditioned by personal characteristics, prior experiences, attitudes, and psychological factors (Negm et al., 2025a; Pot et al., 2021). From the perspective of the Capability Approach, calculated accessibility aligns with the top-down aggregate perspective, approximating what the transport and land-use system makes available, while perceived accessibility aligns with the bottom-up disaggregate perspective, reflecting whether individuals can actually convert those resources into meaningful access given their particular conversion factors (Vecchio and Martens, 2021).

Individual characteristics and personal resources, including sociodemographic characteristics, mobility means, attitudes and preferences, and previous experience, have been shown to shape perceived accessibility (El Murr et al., 2023; Fu et al., 2024; Pot et al., 2023; Tanimoto and Hanibuchi, 2021; Vafeiadis and Elldér, 2024; van der Vlugt et al., 2019). This means that two individuals with similar calculated accessibility levels may perceive their access differently depending on who they are and how they travel. Socially disadvantaged groups may face unmet accessibility needs due to financial constraints, inadequate service, or physical barriers, despite seemingly adequate calculated accessibility (Karner et al., 2024). These differences could be difficult to capture at the aggregate level, requiring the nuances of perceptions at the individual level, underscoring that a group-differentiated analysis attending to both calculated and perceived dimensions is necessary if accessibility standards are to reflect the diversity of circumstances through which people engage with transport systems.

2.3. Towards minimum and sufficient accessibility thresholds

What constitutes a sufficient level of accessibility remains an open and context-sensitive question. In this article, we argue two main points. The first is that sufficiency should not be synonyms with the minimality concept. These should be set as two different thresholds, this has been argued by Hananel and Berechman (2016) where they explained the notion that the thresholds aiming at minimum can be too low, preventing many from living a full and free life. The second point is that in addition to calculated accessibility, perceptions of accessibility should play a major role in determining these thresholds (Pot, 2025). To our knowledge, no study has incorporated the notion of perceived accessibility in combination with calculated accessibility to set thresholds for minimum and sufficient accessibility. Our study aims to fill the gap by providing a methodology to set these thresholds as descriptive benchmarks.

3. Data

This research focuses on identifying the PMA and PSA thresholds in Canadian regions based on calculated and perceived accessibility levels and examines their influence on travel behaviour. To achieve this goal, we use survey data from the Canadian Mobility Survey (CMS) to account for perceived accessibility and travel behaviour, and we pair it with calculated accessibility by PT for each participant's home location measured at the period of survey data collection.

3.1. Survey data

We use data from the CMS, a bilingual online travel survey conducted in Fall 2024 across 12 Census Metropolitan Areas (CMAs) of varying sizes in Canada. The survey covers three large regions with populations over two million: Toronto, Montréal, and Vancouver; three mid-size regions with populations over one million: Ottawa–Gatineau, Calgary, and Edmonton; and six smaller regions with populations under one million: Québec, Winnipeg, Hamilton, Halifax, Victoria, and Saskatoon (Fig. 1). For the CMS, recruitment was performed using a variety of strategies including online social media advertisement, the distribution of flyers, radio interviews, and a public opinion company, as recommended by Dillman et al. (2014).

A thorough multi-step data-cleaning procedure was applied to the survey data. The cleaning process used exclusion criteria based on participants' IP and e-mail addresses, location pins of home, work and/or school, the time it took to complete the survey, reported frequency of weekly travel, and other quality checks. Full details of the cleaning and validation procedure are outlined in Negm et al. (2025b).

For this study, we use variables for participants' perceived accessibility, weekly travel behaviour, residential self-selection, travel identity and attitude, socioeconomic characteristics, and home location. The perceived accessibility questions were designed based on the definition of perceived accessibility by Negm et al. (2025a) and previous studies by Vafeiadis and Elldér (2024) and Vafeiadis (2024). Participants were asked to rate their agreement with the mode- and destination-specific statement: "By [mode], I can easily access my desired destination for [purpose]" on a 4-point Likert scale from strongly disagree to strongly agree. For the purpose of this paper, the scale was converted into a binary variable with positive and negative responses. This statement was presented a total of six times, corresponding to two travel modes, walking and PT, and three destination types: grocery shopping, healthcare, and leisure.

Perceived accessibility was combined for walking and PT for each purpose. It was considered positive if participants reported a positive response for walking and/or PT. This approach accounts for participants who reported lower perceived accessibility by PT due to the proximity of their destinations, which can make transit unrealistic, while still reporting positive perceived accessibility by walking.

Fig. 1. Surveyed regions in the CMS.

For weekly travel behaviour, we asked the participants the number of trips they performed in the last week for shopping, healthcare, and leisure by each of the four travel modes: car, transit, walking, and cycling. In this study, we excluded participants who made less than four trips as they were considered insufficiently mobile and their perceptions of accessibility could be strongly influenced by their limited mobility. The excluded sample ($N = 996$) tends to be older, more likely to report a disability, and in some regions more likely to be low-income compared to the maintained sample (see Appendix A for descriptive statistics). The inclusion of this sample would risk conflating personal mobility constraints with transport environment constraints, introducing noise into the perceived accessibility measure. To account for travel identity, participants rated their agreement with the statement: "I consider myself a [mode user]" for driving, transit user, walking, and cycling. Participants could select multiple modes (e.g., "I consider myself a transit user and a pedestrian").

To classify participants into income groups, we first use the most recent Canadian census (Statistics Canada, 2022a) to identify the household income corresponding to the 30th percentile of the income distribution in each region, which was considered the low-income threshold. This threshold ranged from CAD 64,000 to CAD 90,000 across regions and was rounded to the nearest CAD 30,000 to align with the survey's income categories (reported in CAD 30,000 intervals). A binary variable was then created to distinguish low-income and other-income households: participants whose income category upper bound was less than or equal to the rounded regional threshold were classified as low-income, and all others as other-income.

The cleaning and validation process resulted in a total of 15,960 participants across the 12 regions, with regional samples ranging from 711 to 2036 participants.

3.2. Calculated accessibility metrics

Accessibility has been extensively used to link land use to transport systems, assessing how they benefit the population in reaching various opportunities via different transport modes (El-Geneidy and Levinson, 2022; Geurs and Van Wee, 2004; Levinson and Wu, 2020). Cumulative opportunities and gravity-based measures are among the most widely used accessibility metrics in research and practice (Boisjoly and El-Geneidy, 2017). The cumulative opportunities measure, in particular, is favored due to its ease of interpretation and communication to the public and policymakers (El-Geneidy and Levinson, 2022). It also shows high-correlation with the more complex gravity-based measures, at least in the North American context (Giannotti et al., 2021; Kapatsila et al., 2023; Palacios and El-Geneidy, 2022), suggesting that cumulative opportunities is sufficient to represent the built environment adequately.

In this study, we use cumulative opportunities measures of employment accessible by PT to represent calculated accessibility. While perceived accessibility in this study focuses on specific destination types, employment accessibility is widely used as a proxy for the overall diversity and quantity of opportunities accessible in a given area (Alousi-Jones and El-Geneidy, 2025; Deboosere and El-Geneidy, 2018; El-Geneidy and Levinson, 2022; Rodrigue et al., 2023). This is because employment centres tend to co-locate with essential destinations such as grocery stores, healthcare facilities, and leisure amenities, meaning that areas with high job accessibility also tend to offer broad access to the services captured by our perceived accessibility measures. This decision was further motivated by our aim to develop holistic accessibility thresholds that reflect the overall range of opportunities accessible by PT, rather than thresholds tied to specific destination types.

Calculated accessibility to jobs by PT at the Dissemination Area (DA) level was computed using the number of available jobs, DA-level spatial points, General Transit Feed Specification (GTFS) data, and OpenStreetMap networks. We first identify the number of jobs in each Census Tract (CT) across the 12 regions using the Canadian Commuting Flows (CCF) data, which track commutes from CT of residence to CT of work (Statistics Canada, 2017). Although the most recent CCF was collected in 2021, we used the 2016 data because it provides a more representative depiction of typical post-pandemic commuting patterns. The 2021 flows are heavily influenced by the rise in telecommuting and the overall decline in commuting during the pandemic. To provide finer spatial granularity, the jobs at the CT level were proportionally allocated to the DAs based on land area. This approach was preferred instead of using commuting flows at the DA level because, although Statistics Canada provides data at this finer resolution, it is subject to stricter data suppression due to smaller population sizes in DAs.

DA-level spatial centroids were first extracted for each region using census data shapefiles. Some of these centroids were then manually adjusted to better reflect the spatial distribution of the population, as in many instances, the original centroids fell in unpopulated areas or over water. GTFS data for each region's PT agencies were obtained from Transitland using an application programming interface (API) for October 2024, to match the PT services at the time of collecting the CMS. The OpenStreetMap street network was obtained for each region's CMA through BBBike extracts.

To calculate a travel time matrix (TTM) between the DA-level points, we used the r5r package in R with GTFS data and OSM networks as inputs (Pereira et al., 2021). The TTM represents the shortest travel time (TT) between each pair of DA points and was generated for a typical

Wednesday at one-minute intervals during the morning peak period (7:30 a.m. to 8:30 a.m.). To account for schedule variability, we retrieved the median TT across all departure times. The calculated TT includes access and egress times by walking, as well as waiting, in-vehicle, and transfer times, where applicable.

To best represent accessibility within each region, the TT threshold for the cumulative opportunities measure was set based on the mean TT by PT in the region (Statistics Canada, 2022b), rounded to the nearest 5-min interval, following Kapatsila et al. (2023). Specifically, thresholds of 30 min were used for Victoria; 35 min for Québec, Halifax, Saskatoon, and Winnipeg; 40 min for Hamilton and Ottawa–Gatineau; 45 min for Montréal, Calgary, Vancouver, and Edmonton; and 50 min for Toronto. Proportional accessibility was then calculated by dividing accessibility values by the total number of jobs in the region to enable comparisons across regions. For each participant in the CMS, calculated proportional accessibility was linked to the DA of their home location.

3.3. Descriptive statistics

Table 1 and Table 2 present descriptive statistics for the 15,960 participants, classified by region. In the three large regions, the majority of participants report positive perceived accessibility by PT and/or walking to grocery stores, healthcare, and leisure destinations individually, with positive responses ranging from 71% to 85%. However, when combining perceptions across all three purposes, the share reporting positive accessibility drops to 59%–71%. This decline is also observed in mid-size and small regions, reaching as low as 42% for the purpose-combined perceived accessibility, indicating that some participants have positive perceived accessibility to certain basic destinations but not all of them. On average, participants can access between 9% and 20% of jobs in their respective regions; however, this proportional range corresponds to a much wider absolute range of 16,400 to 392,100 jobs, highlighting the importance of using proportional accessibility to account for differences in regional size and labour market scale. Across all regions, driving is the predominant travel mode, followed by walking, and then PT for the three purposes combined during a typical week. The following section delves deeper into the relationship between these three variables.

4. Analysis and results

Our research consists of multiple steps, all stratified by region. First, we identify the PMA and PSA thresholds by examining the relationship between calculated and perceived accessibility levels using binned log-linear regressions (Fig. 2). We then assess the shares of the general and low-income populations that meet these thresholds and visualise the spatial distribution of the two thresholds across lower- and other-income areas. Finally, we examine walking and PT mode shares at the PMA and PSA thresholds using weighted linear regression models that control for socioeconomic factors, residential selection, travel identity, and travel attitudes.

4.1. Defining PMA and PSA thresholds

Within each region, participants were first ordered sequentially by the calculated accessibility values of their home locations. Based on this order, they were grouped into bins of 50 participants to ensure the reliability of and stability of information obtained from the selected groups (occasionally up to 53 to accommodate the full sample), resulting in a minimum of 14 bins in Saskatoon, a maximum of 40 bins in Montréal, and an average of 28 bins per region. The mean calculated proportional accessibility of participants in each bin was then computed and assigned to each bin.

For each bin, a perceived accessibility score (PA-score) was calculated as the percentage of participants who agreed that they could easily access their desired destinations for grocery, healthcare, and leisure

Table 1
Descriptive statistics for large and mid-size regions by mean (standard deviation).

	Toronto		Montréal		Vancouver		Ottawa – Gatineau		Calgary		Edmonton	
N	1950		2036		1612		1764		1052		1254	
Perceived Accessibility by PT and/or Walking [1 = Positive]												
Grocery stores	0.83	(0.38)	0.75	(0.44)	0.84	(0.37)	0.65	(0.48)	0.72	(0.45)	0.7	(0.46)
Healthcare	0.85	(0.36)	0.78	(0.41)	0.85	(0.36)	0.64	(0.48)	0.69	(0.46)	0.7	(0.46)
Leisure	0.82	(0.38)	0.71	(0.46)	0.81	(0.39)	0.59	(0.49)	0.67	(0.47)	0.66	(0.47)
All three destinations	0.71	(0.45)	0.59	(0.49)	0.69	(0.46)	0.42	(0.49)	0.5	(0.5)	0.52	(0.5)
Calculated Accessibility by PT												
Mean commute time in the region	50		45		45		40		45		45	
N of accessible jobs (x10,000)	39.21	(28.82)	24.63	(26.13)	20.04	(14.46)	6.69	(7.64)	9.13	(8.94)	8.0	(7.07)
% of accessible jobs	15.3%	(11.2%)	14.0%	(14.9%)	19.9%	(14.4%)	11.2%	(12.8%)	15.5%	(15.2%)	14.4%	(12.8%)
Travel Behaviour (Weekly to grocery, leisure, and healthcare)												
% of PT trips	18%	(24)	13%	(13)	18%	(25)	7.2%	(18)	9.2%	(22)	10%	(23)
% of walking trips	37%	(30)	27%	(27)	35%	(30)	23%	(29)	24%	(27)	21%	(26)
% of driving trips	36%	(38)	54%	(54)	40%	(38)	62%	(39)	61%	(38)	63%	(38)
Socioeconomic characteristics												
Gender [1 = Woman]	0.52	(0.5)	0.5	(0.5)	0.54	(0.5)	0.58	(0.49)	0.6	(0.49)	0.58	(0.49)
Age	44	(16)	47	(16)	45	(17)	44	(15)	43	(16)	44	(16)
Low-income household [1 = Yes]	0.37	(0.48)	0.24	(0.42)	0.48	(0.5)	0.27	(0.45)	0.47	(0.5)	0.5	(0.5)
Household size	2.47	(1.26)	2.56	(1.31)	2.33	(1.22)	2.56	(1.26)	2.61	(1.33)	2.5	(1.28)
Full time employment [1 = Yes]	0.59	(0.49)	0.59	(0.49)	0.58	(0.49)	0.68	(0.47)	0.6	(0.49)	0.57	(0.49)
Travel and residential variables												
Residing near transit [1 = Important]	0.69	(0.46)	0.6	(0.49)	0.65	(0.48)	0.52	(0.5)	0.46	(0.5)	0.44	(0.5)
Identify as transit and/or pedestrian [1 = Agree]	0.90	(0.3)	0.82	(0.39)	0.90	(0.3)	0.77	(0.42)	0.79	(0.41)	0.76	(0.42)
Know how PT system works [1 = Agree]	0.93	(0.26)	0.89	(0.32)	0.95	(0.22)	0.85	(0.36)	0.86	(0.35)	0.85	(0.35)

Table 2
Descriptive statistics for small regions by mean (standard deviation).

	Québec		Winnipeg		Hamilton		Halifax		Victoria		Saskatoon	
N	1301		1183		993		1100		1004		711	
Perceived Accessibility by PT and/or Walking [1 = Positive]												
Grocery stores	0.64	(0.48)	0.72	(0.45)	0.74	(0.44)	0.67	(0.47)	0.8	(0.4)	0.66	(0.47)
Healthcare	0.72	(0.45)	0.72	(0.45)	0.81	(0.39)	0.7	(0.46)	0.76	(0.43)	0.65	(0.48)
Leisure	0.54	(0.5)	0.69	(0.46)	0.77	(0.42)	0.64	(0.48)	0.72	(0.45)	0.61	(0.49)
All three destinations	0.43	(0.49)	0.51	(0.5)	0.6	(0.49)	0.48	(0.5)	0.6	(0.49)	0.44	(0.5)
Calculated Accessibility by PT												
Mean commute time in the region	35		35		40		35		30		35	
N of accessible jobs (x10,000)	3.36	(3.56)	4.82	(4.39)	4.4	(2.88)	3.06	(3.06)	2.83	(2.25)	1.64	(1.67)
% of accessible jobs	9.0%	(9.5%)	14.0%	(12.8%)	16.1%	(10.5%)	16.9%	(16.9%)	18.8%	(14.9%)	12.9%	(13.1%)
Travel Behaviour (Weekly shopping, leisure, and healthcare)												
% of PT trips	6.2%	(17)	10%	(23)	11%	(20)	8.9%	(21)	8.3%	(19)	8.2%	(22)
% of walking trips	22%	(30)	24%	(28)	28%	(27)	28%	(31)	33%	(31)	20%	(26)
% of driving trips	65%	(39)	59%	(38)	56%	(38)	58%	(40)	48%	(38)	68%	(36)
Socioeconomic characteristics												
Gender [1 = Woman]	0.49	(0.5)	0.59	(0.49)	0.59	(0.49)	0.58	(0.49)	0.54	(0.5)	0.62	(0.49)
Age	48	(15)	44	(16)	43	(16)	46	(16)	50	(18)	43	(17)
Low-income household [1 = Yes]	0.18	(0.39)	0.3	(0.46)	0.5	(0.5)	0.3	(0.46)	0.51	(0.5)	0.58	(0.49)
Household size	2.36	(1.16)	2.58	(1.33)	2.66	(1.36)	2.39	(1.18)	2.25	(1.19)	2.53	(1.3)
Full time employment [1 = Yes]	0.65	(0.48)	0.58	(0.49)	0.58	(0.49)	0.59	(0.49)	0.48	(0.5)	0.5	(0.5)
Travel and residential variables												
Residing near transit [1 = Important]	0.48	(0.5)	0.49	(0.5)	0.48	(0.5)	0.46	(0.5)	0.49	(0.5)	0.35	(0.48)
Identify as transit and/or pedestrian [1 = Agree]	0.70	(0.46)	0.81	(0.39)	0.83	(0.38)	0.79	(0.41)	0.86	(0.35)	0.78	(0.41)
Know how PT system works [1 = Agree]	0.87	(0.33)	0.88	(0.32)	0.84	(0.37)	0.85	(0.36)	0.88	(0.32)	0.77	(0.42)

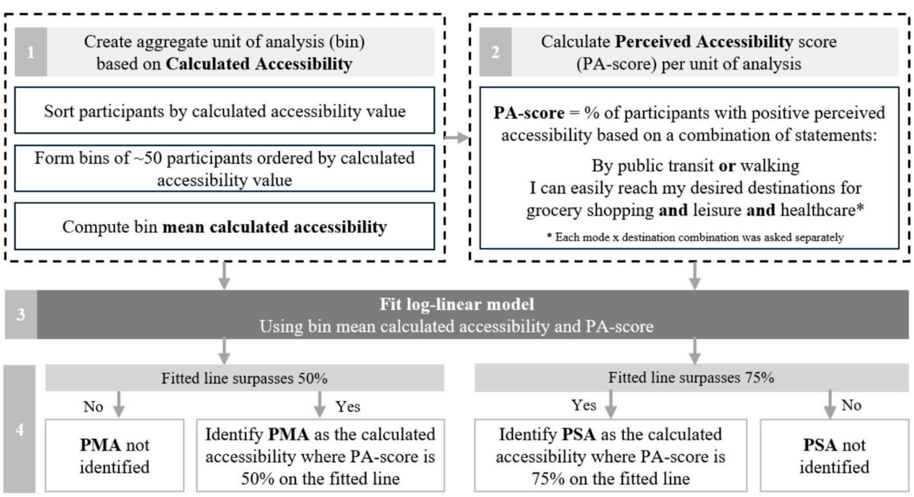

Fig. 2. Methodological framework for identifying PMA and PSA using calculated and perceived accessibility.

separately, as well as for all three purposes combined, by walking and/or PT. Since the PA-score is computed as a percentage of agreement within a group, it converts individual binary responses into a continuous group-level measure.

Calculated accessibility by PT was used as a proxy for both PT and walking accessibility. This is because walking is explicitly incorporated into the travel time (TT) calculations (see Section 3.2); when walking is faster than PT, the TT in the accessibility calculations is the walking TT. Additionally, there is a strong positive correlation ($r = 0.73$) in our sample between PT accessibility and Walk Score, a validated measure of neighbourhood walkability and amenity density (Carr et al., 2011). This association suggests that PT-based calculated accessibility reasonably captures both PT and walking accessibility in this study. Based on these groupings, binned log-linear regression analyses were conducted.

Each group's PA-score was plotted against its calculated proportional accessibility and log-linear models were fitted for each travel purpose as well as for all purposes combined, as displayed in Fig. 3. The lines in shades of green correspond to the fitted log-linear models for each travel purpose, while the orange line represents the model estimated using all three purposes combined. The goodness of fit (R^2) of the combined-purposes models ranges from 0.46 to 0.86, with an average of 0.69. These goodness-of-fit values indicate that the log-linear models provide a sufficiently good fit to reliably identify the intended minimum and sufficient thresholds.

We identified the PMA and PSA at the intersection of the combined model's fitted line with the 50% and 75% PA-score (representing the

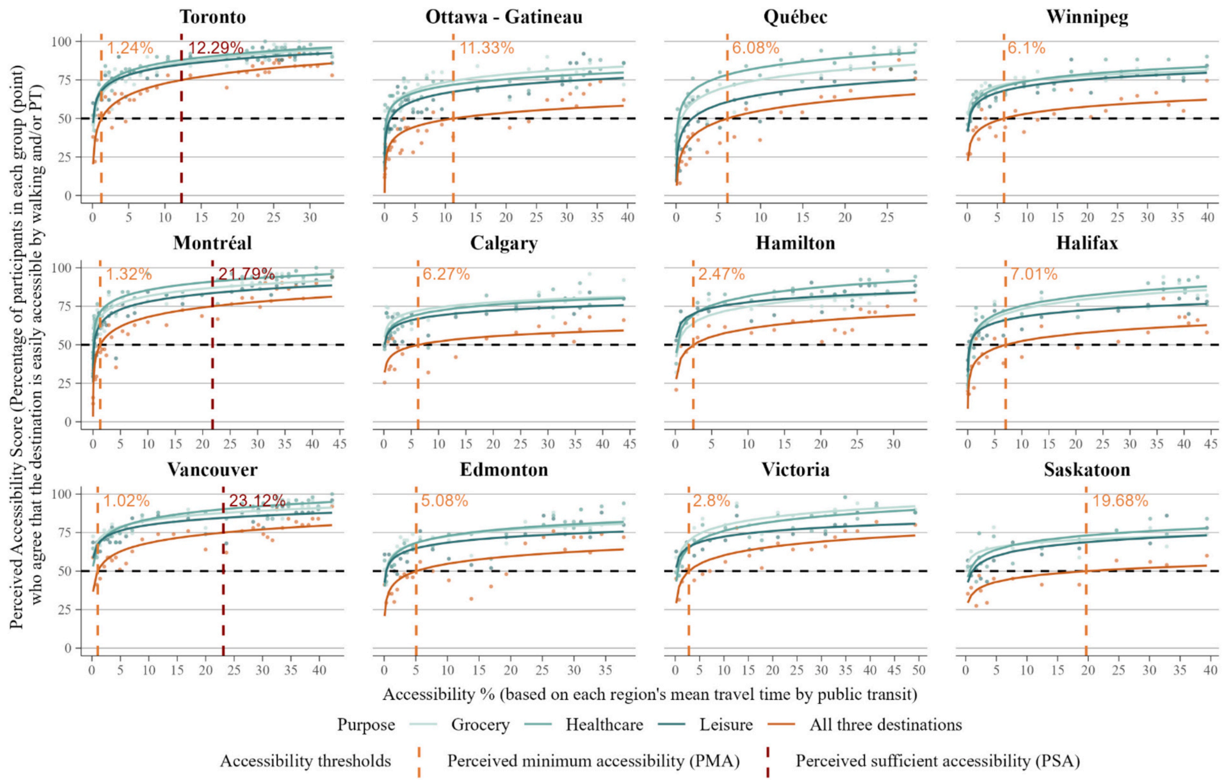

Fig. 3. Perceived minimum accessibility (PMA) and Perceived sufficient accessibility (PSA) by region based on perceived accessibility score (PA-score) and calculated accessibility.

percentage of participants with positive perceived accessibility), respectively. As the combined model line only surpasses the 75% score in the large regions, we only identified PSA for these regions.

To assess the sensitivity of the PMA and PSA estimates to the choice of threshold, we tested alternative PA-score cutoffs ranging from 40% to 60% for the PMA and from 65% to 85% for the PSA in 5 percentage point increments, computing the shift in estimated accessibility values per step for each region (Appendix B). Results confirm that estimated accessibility values remain stable at or below the chosen cutoffs but diverge rapidly above them, identifying PMA at 50% and PSA at 75% as practical breakpoints that converge with their grounding in majority and supermajority consensus conventions, respectively. We nonetheless acknowledge that these remain practically imposed breakpoints rather than natural breakpoints in the distribution, and that selecting different thresholds would yield different results.

Table 3 shows the PMA diagnostics as a percentage and as a number of jobs accessible within the region's average travel time, as well as the percentage of the general and low-income population meeting that threshold. Low-income population statistics were calculated using the thresholds described in Section 3.1, without rounding to the nearest CAD 30,000, because this analysis was performed at the dissemination area (DA) level, which provides detailed median income for each DA. This approach allowed for identification of low- and other-income DAs and their corresponding populations. In the large regions (Toronto, Montréal, and Vancouver), the PMA threshold ranges between 1.02 and 1.32% of accessible jobs within average travel time by PT in the region, translating to 10,000–31,800 jobs. This threshold slightly increases in Hamilton and Victoria to range between 2.5 and 2.8% (4200–6700 jobs). For Edmonton, Calgary, Québec, Winnipeg, and Halifax, the PMA ranges between 5 and 7% (12,700–36,600 jobs). Ottawa-Gatineau and

Table 3
Perceived Minimum Accessibility (PMA) diagnostics.

	Total jobs [x1,000]	**Total pop.** [x1,000]	**Low-income pop.** [x1,000]	**PMA** [% (Nx1,000 of jobs in region]		**Total pop. With PMA** [% (Nx1,000)]		**LI pop. With PMA** [% (Nx1,000)]	
Large regions									
Toronto	2566	6202	1910	**1.2%**	(31.8)	**65.5%**	(4064)	**92.7%**	(1770)
Montréal	1753	4292	1291	**1.3%**	(23.2)	**59.4%**	(2549)	**85.3%**	(1102)
Vancouver	1003	2643	814	**1.0%**	(10.2)	**86.1%**	(2276)	**97.7%**	(795)
Mid-size regions									
Ottawa - Gatineau	595	1488	456	**11.3%**	(67.4)	**16.7%**	(248)	**35.8%**	(163)
Calgary	584	1482	452	**6.3%**	(36.6)	**29.4%**	(436)	**55.5%**	(251)
Edmonton	552	1418	426	**5.1%**	(28.0)	**34.3%**	(486)	**70.1%**	(299)
Small regions									
Québec	375	839	253	**6.1%**	(22.8)	**27.2%**	(228)	**64.0%**	(162)
Winnipeg	343	835	258	**6.1%**	(20.9)	**38.2%**	(319)	**72.2%**	(186)
Hamilton	273	785	241	**2.5%**	(6.7)	**57.1%**	(449)	**89.8%**	(217)
Halifax	181	466	143	**7.0%**	(12.7)	**23.9%**	(111)	**48.2%**	(69)
Victoria	151	397	121	**2.8%**	(4.2)	**51.1%**	(203)	**82.4%**	(100)
Saskatoon	127	317	97	**19.7%**	(25.0)	**14.6%**	(47)	**36.3%**	(35)

Saskatoon have the highest PMA reaching 11.3% and 19.7%, respectively. Ottawa-Gatineau's PMA translates to the highest job count requirement among all regions (67,400 jobs).

In terms of population coverage, Vancouver has the best performance with the lowest PMA among all regions (1.0%) covering 86.1% of its population and 97.7% of its low-income population. It is followed by Toronto, Montréal, Hamilton, and Victoria where the PMA serves at least 50% of their population and 82% of their low-income population. Meanwhile, all other regions' PMA serves less than 40% of the population. Regardless, most of these regions still serve a majority of the low-income population, except for Ottawa-Gatineau and Saskatoon. Despite their high PMA values, these two regions' PMA only meet about 14–17% of their total population and 36% of their low-income population.

Table 4 presents the same diagnostics as Table 3, however for PSA in large regions, as they are the only ones where the 75% PA-score was attainable. The PSA threshold is exponentially higher than the PMA for these regions, reaching 12.3%, 21.8%, and 23.1% in Toronto, Montréal, and Vancouver, respectively. These thresholds are represented by a range of 232,000–315,000 jobs. These thresholds are available for less than 25% of the population in each of the regions, and a much lower range of only 29–43% of the low-income population, compared to the PMA.

Fig. 4 and Fig. 5 display the spatial distribution of perceived minimum and sufficient accessibility through classifying the DAs based on whether their calculated proportional accessibility values meet the PMA and PSA thresholds in their respective regions, stratified by income group. As portrayed in the tabulated diagnostics, large regions achieve widespread coverage of minimum accessibility for both low- and other-income groups across most parts of their CMAs, with gaps primarily at the urban periphery. However, perceived sufficient accessibility is largely concentrated in central areas, predominantly along rapid transit corridors with high destination density. As for the mid-size and small regions, PMA coverage is largely confined to central areas, leaving many low- and other-income census tracts without even basic access to essential destinations.

4.2. PMA, PSA, and travel behaviour

To assess the connection between the identified thresholds and travel behaviour, we ran weighted linear regressions for each region, with the dependent variable being the percentage of weekly trips performed by walking and PT combined to grocery stores, healthcare, and leisure destinations. Weighted regression models accounted for potential sampling bias in the cleaned survey data. We calculated the weights using the anesrake R package (Pasek, 2018), following an iterative ranking process (DeBell and Krosnick, 2009). The weights were calculated to match the census-tract information of age, income, gender, and commute mode obtained from the 2021 Canadian census (Statistics Canada, 2022a), as well as the most recent commute mode share data retrieved from Statistics Canada (2024). These models account for socioeconomic characteristics, travel-attitude and identity factors, residential selection, and most importantly for this research, calculated accessibility.

All models were estimated separately by region to ensure independence of observations. Variance inflation factors (VIF) confirmed the absence of multicollinearity across all models (all VIF < 2). As the dependent variable captures the percentage of weekly trips made by public transit or walking, a notable share of observations falls at 0% and 100%. We retained this continuous measure over a binary specification to preserve variation in travel behaviour. A logit transformation was tested as a robustness check and did not yield substantively different results; we therefore retain the simpler OLS specification for ease of interpretation. The travel behaviour models are intended as exploratory illustrations of the practical relevance of the identified thresholds.

For brevity, Table 5 presents a subset of results for three representative regional groups: Toronto (large region), Ottawa–Gatineau (mid-size region), and Halifax (small region). The complete set of regression results is provided in Appendix C. The model fit (R^2) in the three displayed models ranged from 0.35 to 0.37, indicating moderate explanatory power, which is typical for models of travel behaviour. In all models, four factors are consistently statistically significant: employment statuses, travel identity, perceived accessibility, and calculated accessibility by PT. Other variables are statistically significant in most, but not all, regions, highlighting regional heterogeneity and justifying the estimation of separate models to improve accuracy.

Consistent with previous literature, older participants tend to have a lower walking and PT mode share, ceteris paribus (Brown et al., 2016; Ghani et al., 2016; Newbold and Scott, 2018; Ozbilen et al., 2024; Ravensbergen et al., 2023). Full-time employment is associated with a decrease of 7.8 to 9.2 percentage points in walking and PT mode share, all else held constant. Accounting for residential self-selection is essential to avoid overestimating the influence of the built environment on travel behaviour (Cao et al., 2009). In our models, residential self-selection is captured through respondents' stated preference for residing near PT which is positively associated with walking and PT use. The stated preference for residing in a walkable neighbourhood was also tested but was not statistically significant across regions. Knowing how the PT system operates in one's region is associated with an increase of approximately 5 percentage points in walking and PT mode share ceteris paribus. Travel identity is a crucial control variable in our models, as previously discussed by Negm and El-Geneidy (2025). Identifying as a pedestrian and/or transit user is associated with an increase of approximately 13.7 to 19.9 percentage points in weekly walking and PT mode share, holding other variables at their mean values. Consistent with prior research (Negm and El-Geneidy, 2025), having positive perceived accessibility by walking and/or PT is associated with a statistically significant increase of 10.3 to 13.6 percentage points in mode share, ceteris paribus.

The key variable of interest is calculated accessibility. Prior research has established calculated accessibility as a predictor of walking mode share at the local scale (Elldér et al., 2020; Manaugh and El-Geneidy, 2011) and PT mode share on the regional scale (Cui et al., 2020; Moniruzzaman and Páez, 2012; Negm and El-Geneidy, 2024; Owen and Levinson, 2015). Across all regions, proportional calculated accessibility by PT is statistically significant and positively associated with walking and PT mode share to essential destinations, although the magnitude varies regionally. A one-percentage-point increase in jobs accessible by PT is associated with a 0.6 to 1.1 percentage-point increase in walking and PT mode share, all else kept the mean value.

To specifically investigate the relationship of mode share with PMA and PSA, we conducted a marginal effects analysis using the estimated regional models. We defined a representative profile: a 45-year-old full-

Table 4
Perceived sufficient accessibility PSA diagnostics (for large regions only).

	Total jobs [x1,000]	Total pop. [x1,000]	Low-income pop. [x1,000]	PSA [% (Nx1,000 of jobs in region]		Total pop. With PSA [% (Nx1,000)]		LI pop. With PSA [% (Nx1,000)]	
Large regions									
Toronto	2566	6202	1910	**12.3%**	(315)	**17.4%**	(1082)	**29.0%**	(553)
Montréal	1753	4292	1291	**21.8%**	(382)	**23.3%**	(999)	**43.0%**	(555)
Vancouver	1003	2643	814	**23.1%**	(232)	**23.4%**	(620)	**38.6%**	(314)

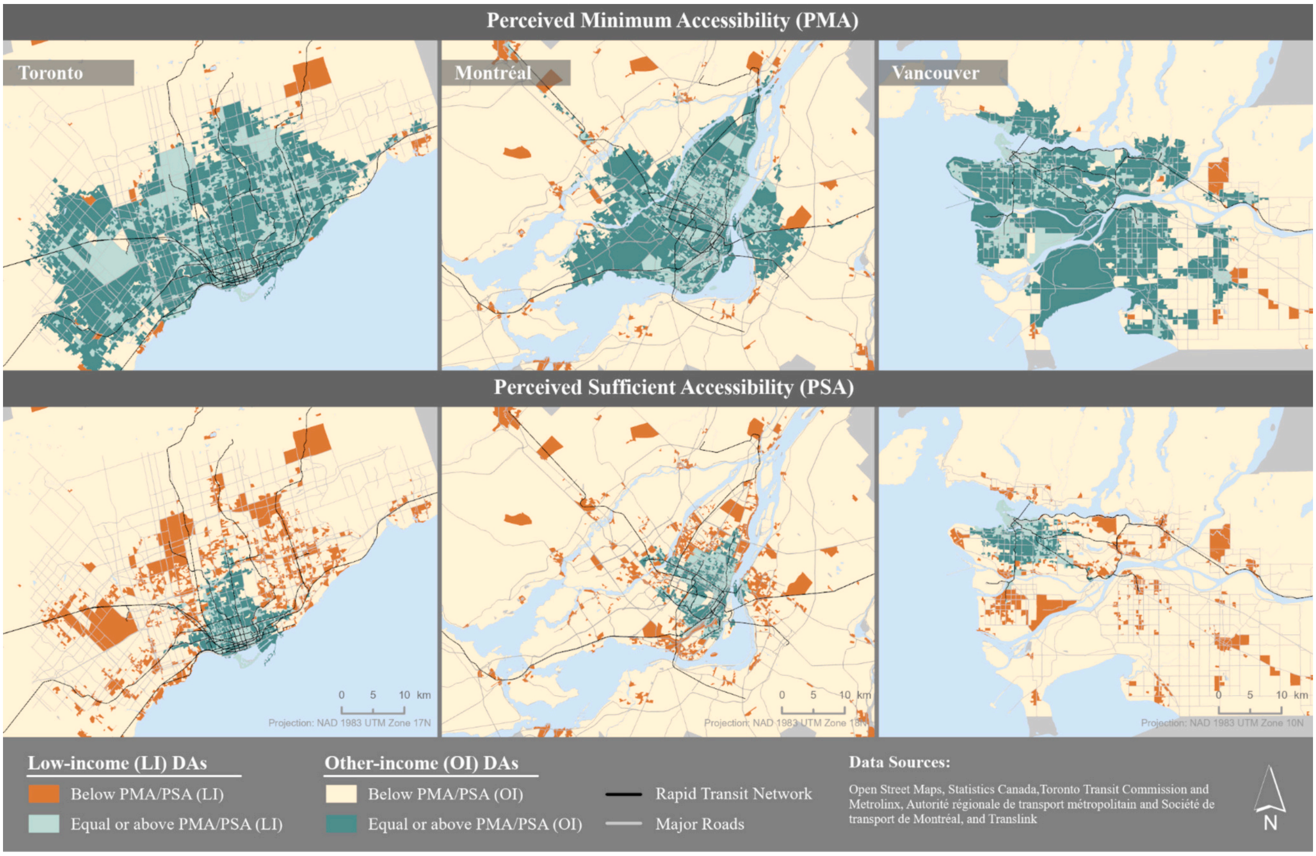

Fig. 4. DAs in large regions classified by whether their proportional calculated accessibility meets the PMA and PSA thresholds, by income group.

time employed man in a two-person household who identifies as a transit user, considers proximity to PT important in residential choice, reports knowing how the PT system operates in his region, and have positive perceived accessibility. The analysis was conducted for both low-income and other-income households. Predicted mode shares for additional profiles combining income group and travel identity are provided in Appendix D.

Fig. 6 presents the predicted weekly walking and PT mode share as calculated proportional accessibility increases for low- and other-income individuals. The mode share difference between income groups is most pronounced in the three large regions in addition to Victoria and Halifax with people in low-income households making 3.7 to 5 percentage points more trips than in other-income ones (as shown in Appendix C), This is illustrated by the green lines being consistently higher than the grey ones in the figure. These higher mode shares among low-income households reflect greater reliance on walking and public transport, suggesting that accessibility thresholds may have stronger behavioural consequences for these groups (Freeland et al., 2013; Negm and El-Geneidy, 2024).

For brevity, we report the low-income household case. In large regions, PMA is associated with approximately 33% of walking and PT mode share on average, while PSA is associated with a heightened range of approximately 46% mode share on average. In mid-size and small regions, PMA is associated with a range of 24 to 39% mode share, with an average of 32%, similar to the large regions. Overall, PMA achieves basic levels of walking and PT mode share, while PSA (as shown in the large regions) dramatically increases this mode share.

Mode share targets are a common metric in transport planning. For example, the cities of Montréal, and Vancouver aim for 75% and 67% of trips to be conducted by PT and active modes, respectively (City of Vancouver, 2012; Ville de Montréal, 2025). Our analysis shows that these targets are unattainable if planning focuses solely on PMA, which can only provide basic access to destinations. Planning for the PSA in these large regions have the potential of approaching the planned mode share targets and achieving sustainable goals. While we do not specify the PSA for mid-sized and small regions since the PA-score rarely exceeded 75% (Fig. 3), planning beyond the PMA in these regions remains important to increase sustainable mode share and promote equitable access.

5. Conclusion

Paving the way for the implementation of accessibility in practice, this paper provides a methodology to identify region-specific PMA thresholds that allow the population basic access to essential destinations, as well as PSA thresholds that ensure convenient access to these destinations. Rather than prescribing normative standards, these benchmarks are grounded in observed distributions of calculated and perceived accessibility, offering a replicable and transferable tool to support transport planning and evaluation. In doing so, the paper responds to calls for more operational approaches to accessibility that can be readily applied in practice (Karner et al., 2024; Martens, 2016b; Pereira et al., 2017; Ryan and Martens, 2023).

Using 12 regions in Canada as case studies and relying on nationwide transport survey data, we examine the share of the population meeting PMA and PSA levels. We find that large metropolitan regions such as Toronto, Montréal, and Vancouver have relatively small gaps to close in achieving PMA for their low-income populations, enabling basic access to essential destinations by walking or PT However, further efforts are required to extend this basic access to the entire population. In contrast, substantially greater efforts are needed to close PSA gaps. For example, in Toronto, only 29% of the low-income population surpasses the PSA threshold.

Our analysis highlights critical transport and land use planning

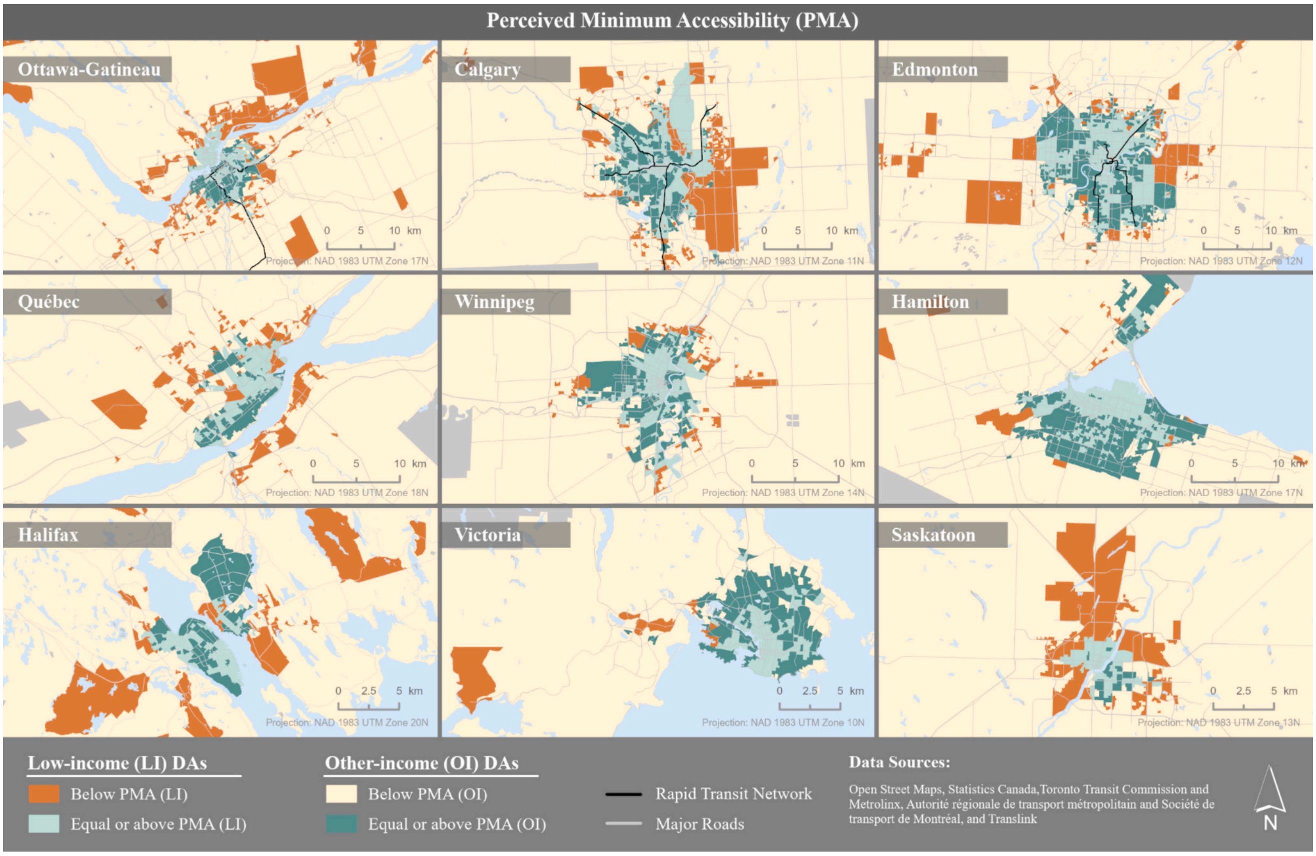

Fig. 5. DAs in mid-size and small regions classified by whether their proportional calculated accessibility meets the PMA thresholds, by income group.

Table 5
Weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable (Subset from each region size).

	Toronto (Large region)			Ottawa - Gatineau (Medium region)			Halifax (Small region)		
Predictor	Coef.		CI	Coef.		CI	Coef.		CI
Intercept	6.47		−1.50–14.44	**6.41**		−0.51–13.32	4.85		−4.20–13.91
Socioeconomic characteristics									
Gender [Woman]	2.00		−0.48–4.48	−1.38		−3.68–0.93	**−3.87**	**	−6.80 to −0.94
Age	**−0.13**	**	−0.21 to −0.05	**−0.18**	***	−0.26 to −0.11	−0.06		−0.16–0.03
Low-income household	**3.82**	**	1.22–6.43	2.35		−0.25–4.96	**4.46**	**	1.30–7.62
Household size	**−1.13**	*	−2.13 to −0.13	−0.33		−1.35–0.69	0.31		−0.98–1.60
Full time empl.	**−9.23**	***	−12.03 to −6.43	**−7.80**	***	−10.46 to −5.15	**−8.54**	***	−11.82 to −5.27
Travel and residential variables									
RSS near transit	1.48		−1.26–4.22	2.43		−0.05–4.92	**7.67**	***	4.53–10.82
Know how PT system work	**5.24**	**	1.32–9.15	**5.20**	**	2.10–8.30	−1.62		−5.58–2.34
Ident: PT user and/or Ped.	**19.96**	***	16.69–23.22	**13.71**	***	10.98–16.44	**15.56**	***	12.16–18.95
Perceived Accessibility									
By walking and/or PT to all destinations	**10.56**	***	7.90–13.22	**13.63**	***	11.12–16.14	**10.30**	***	7.20–13.41
Calculated Accessibility by PT									
% of jobs access. by PT	**1.10**	***	0.97–1.24	**0.78**	***	0.67–0.90	**0.55**	***	0.44–0.65
Observations	**1950**			**1764**			**1100**		
R 2 / R 2 adjusted	**0.373 / 0.369**			**0.354 / 0.350**			**0.349 / 0.344**		

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

challenges in several regions. For instance, in Ottawa–Gatineau, the 11.3% PMA level translates into an extremely high job count (67,400 jobs) needed just to achieve basic access to essential destinations, with only 16.7% of the total population and 35.8% of the low-income population meeting that threshold. These diagnostics are crucial for identifying regions that require targeted policy intervention.

When examining the relationship between PMA and PSA and weekly walking and PT mode share to shopping, leisure, and healthcare destinations, we find that substantially higher levels of sustainable mode share can be achieved when planning targets sufficient rather than merely minimum accessibility. This finding highlights the need for stronger planning ambitions to achieve regional sustainable mode share targets (Negm and El-Geneidy, 2024).

This research provides practical value for planning and transport professionals seeking to promote equitable access through transparent metrics and replicable benchmarks. Based on the identified thresholds, planners and policymakers should prioritize improvements in underserved areas by enhancing public transport systems, improving

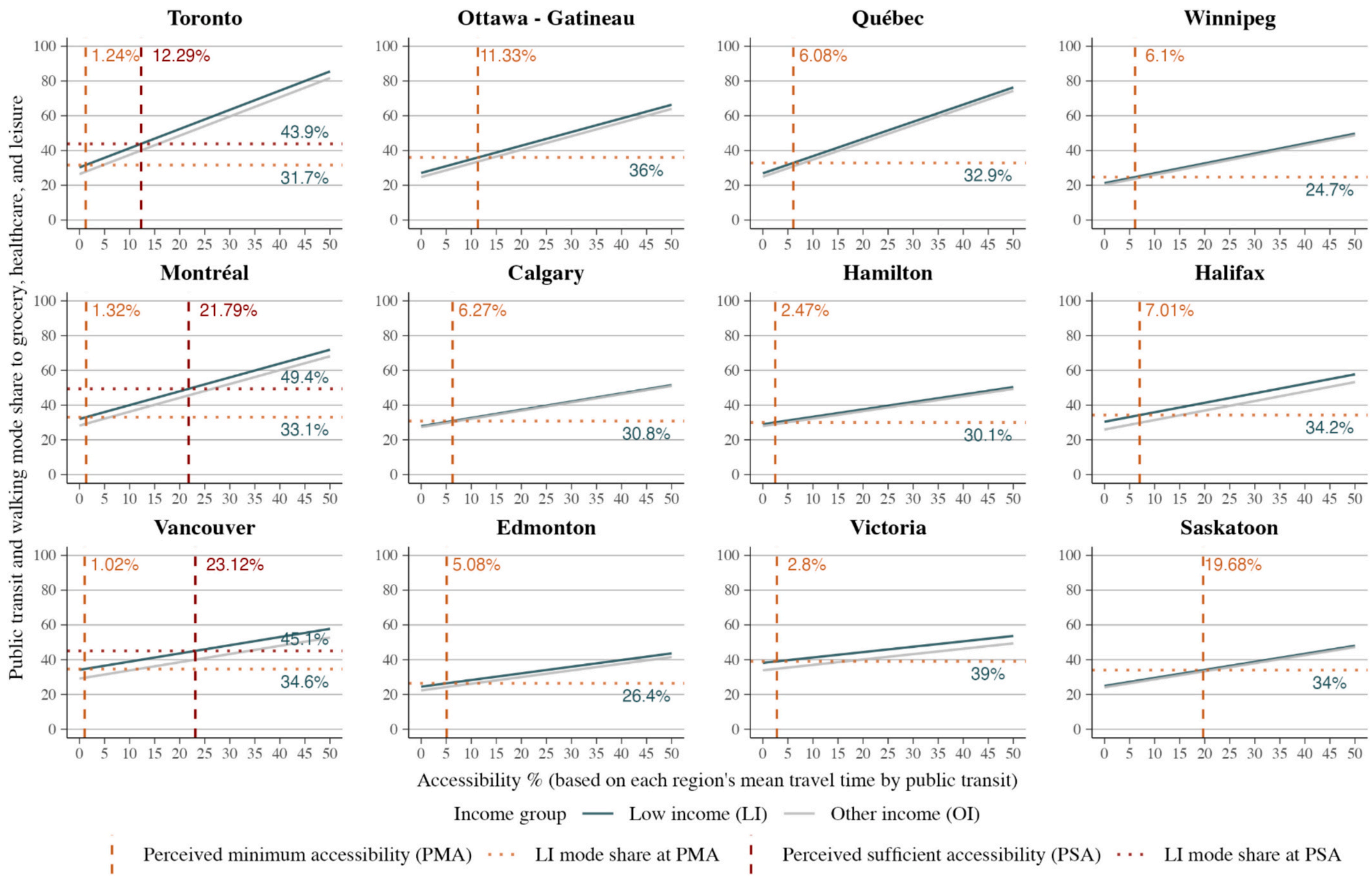

Fig. 6. Marginal effects of accessibility on PT and walking mode share, with reference lines showing the low-income sample's mode share at PMA and PSA.

walkability and street design, and conducting outreach campaigns that introduce residents to available transit options. Perceived accessibility plays a central role in these metrics; interventions that increase perceived accessibility scores can make PMA and PSA thresholds more attainable.

A consideration when using perceived accessibility to inform thresholds is that perceptions may not fully capture unmet needs, particularly among disadvantaged groups who may have adapted their expectations under constrained conditions. Clifton and Moura (2017) describe this phenomenon in the context of latent and suppressed demand. In this sense, thresholds derived from perceived accessibility may partly reflect current patterns of experienced access rather than an ideal level of sufficiency. We therefore propose that PMA and PSA be interpreted as descriptive benchmarks grounded in observed distributions of calculated and perceived accessibility, rather than normative standards of what access ought to be. Their value lies in providing an empirically grounded and replicable reference point to support planning decisions, complementing rather than replacing broader deliberative processes for defining sufficient access.

We acknowledge that perceived accessibility and travel behaviour are theoretically interdependent, as one's perceptions of accessibility may be shaped by their existing travel patterns and vice versa. The regression framework used in this study does not fully accommodate this bidirectionality, and results should therefore be interpreted as exploratory. Future research could employ structural equation modelling (SEM) to better unravel the reciprocal relationships between perceived accessibility and travel behaviour (Negm et al., 2025a).

Future research could explore whether income- or gender-stratified analyses yield different accessibility thresholds. It could develop purpose-specific accessibility thresholds for destination types such as grocery stores, healthcare, and leisure, which would allow for more direct comparisons with perceived accessibility measures. Moreover, while the quartile-based approach used to define PMA and PSA ensures transparency and replicability, it relies on the availability of perceived accessibility data, which may not be available in all regions. Future research could also focus on low-mobility populations, such as those making fewer than four trips per week, who tend to be older, more likely to report a disability, and in some regions more likely to be low-income. Dedicated studies on this group, potentially employing mixed methods approaches combining survey data with qualitative interviews, would better capture their lived experience of accessibility. Finally, while this study focuses on the regional scale, the proposed methodology could be extended to a local scale, where walking- or cycling- specific calculated accessibility measures are paired with perceived accessibility to identify perception-based thresholds for these modes.

CRediT authorship contribution statement

Hisham Negm: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Ahmed El-Geneidy:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

None

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Appendix A. Appendix

Table A.1
Descriptive statistics (mean) of the dropped sample (996 participants who made fewer than four trips per week).

	TOR	MTL	VAN	OTT	CAL	EDM	QUE	WIN	HAM	HAL	VIC	SAS
N	99	183	92	91	80	75	73	81	55	63	42	62
Gender [1 = Woman]	0.54	0.52	0.62	0.62	0.65	0.63	0.53	0.58	0.55	0.62	0.48	0.6
Age	49	56	54	51	52	52	53	53	50	55	58	56
Low-income household [1 = Yes]	0.61	0.3	0.62	0.37	0.57	0.72	0.23	0.37	0.64	0.52	0.62	0.68
Household size	2.2	2.2	2.2	2.4	2.2	2.5	2	2.3	2.5	2	2	2.3
Full time employment [1 = Yes]	0.4	0.48	0.35	0.49	0.34	0.33	0.44	0.32	0.42	0.35	0.36	0.31
Disability [1 = Yes]	0.38	0.24	0.45	0.33	0.31	0.33	0.16	0.4	0.33	0.4	0.45	0.37

Appendix B. Appendix

Table B.1
PA-score steps and their corresponding PMA statistics.

PA-score steps (for defining PMA)	All regions			All regions excluding Saskatoon (outlier)		
	Mean difference in PMA	SD difference in PMA	Max difference in PMA	Mean difference in PMA	SD difference in PMA	Max difference in PMA
40–45%	1.42	1.25	4.61	1.13	0.79	2.82
45–50%	3.18	3.33	12.3	2.35	1.78	6.01
50–55%	7.34	8.98	32.79	5.03	4.25	12.8
55–60%	17.4	24.33	87.44	11.03	10.78	32.95

Table B.2
PA-score steps and their corresponding PSA statistics.

PA-score steps (for defining PSA)	Three largest regions (Toronto, Montreal, Vancouver		
	Mean difference in PSA	SD difference in PSA	Max difference in PSA
65–70%	4.65	1.56	5.75
70–75%	8.21	3.26	10.74
75–80%	14.54	6.65	20.07
80–85%	25.84	13.31	37.5

Appendix C. Appendix

Table C.1
Large regions weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable.

	Toronto		Montréal		Vancouver	
Predictor	Coef.	CI	Coef.	CI	Coef.	CI
Intercept	6.47	−1.50–14.44	**7.28****	0.43–14.14	**10.81****	1.20–20.42
Socioeconomic characteristics						
Gender [Woman]	2.00	−0.48–4.48	1.30	−1.01–3.61	**6.89********	4.05–9.73
Age	**−0.13******	−0.21 to −0.05	**−0.21********	−0.28 to −0.13	**−0.17********	−0.26 to −0.09
Low-income household	**3.82******	1.22–6.43	**3.77******	1.23–6.31	**5.05******	1.95–8.16
Household size	**−1.13****	−2.13 to −0.13	−0.75	−1.69–0.19	**−1.92******	−3.16 to −0.68
Full time empl.	**−9.23********	−12.03 to −6.43	**−7.46********	−9.98 to −4.93	**−10.59********	−13.83 to −7.35
Travel and residential variables						

(*continued on next page*)

Table C.1 (*continued*)

Predictor	Toronto		Montréal		Vancouver	
	Coef.	CI	Coef.	CI	Coef.	CI
RSS near transit	1.48	−1.26–4.22	**6.15*****	3.57–8.74	**6.83*****	3.81–9.85
Know how PT system work	**5.24****	1.32–9.15	1.54	−1.92–5.00	−0.45	−6.02–5.11
Ident: PT user and/or Ped.	**19.96*****	16.69–23.22	**17.16*****	14.19–20.12	**18.29*****	14.49–22.09
Perceived Accessibility						
By walking and/or PT to all destinations	**10.56*****	7.90–13.22	**14.33*****	11.79–16.87	**15.90*****	12.95–18.85
Calculated Accessibility by PT						
% of jobs access. by PT	**1.10*****	0.97–1.24	**0.80*****	0.70–0.89	**0.47*****	0.36–0.58
Observations	**1950**		**2036**		**1612**	
R 2 / R 2 adjusted	**0.373 / 0.369**		**0.385 / 0.383**		**0.329 / 0.325**	

* p < 0.05 ** p < 0.01 *** p < 0.001.

Table C.2
Mid-size regions weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable.

Predictor	Ottawa - Gatineau		Calgary		Edmonton	
	Coef.	CI	Coef.	CI	Coef.	CI
Intercept	**6.41**	−0.51–13.32	**13.45****	3.97–22.93	−0.33	−7.56–6.90
Socioeconomic characteristics						
Gender [Woman]	−1.38	−3.68–0.93	**−2.99***	−5.97 to −0.01	1.83	−0.55–4.22
Age	**−0.18*****	−0.26 to −0.11	**-0.11***	−0.21 to −0.00	−0.01	−0.09–0.07
Low-income household	2.35	−0.25–4.96	0.50	−2.73–3.73	2.13	−0.39–4.64
Household size	−0.33	−1.35–0.69	**−1.60***	−2.85 to −0.34	−0.65	−1.62–0.32
Full time empl.	**−7.80*****	−10.46 to −5.15	**−8.35*****	−11.66 to −5.04	**−4.26****	−6.85 to −1.67
Travel and residential variables						
RSS near transit	2.43	−0.05–4.92	**5.32****	2.11–8.53	**4.95*****	2.21–7.69
Know how PT system work	**5.20****	2.10–8.30	−0.81	−4.90–3.28	−0.20	−3.37–2.98
Ident: PT user and/or Ped.	**13.71*****	10.98–16.44	**16.88*****	13.42–20.34	**15.63*****	12.88–18.39
Perceived Accessibility						
By walking and/or PT to all destinations	**13.63*****	11.12–16.14	**8.83*****	5.72–11.94	**8.51*****	6.02–11.00
Calculated Accessibility by PT						
% of jobs access. by PT	**0.78*****	0.67–0.90	**0.47*****	0.36–0.58	**0.38*****	0.27–0.49
Observations	**1764**		**1052**		**1254**	
R 2 / R 2 adjusted	**0.354 / 0.350**		**0.271 / 0.264**		**0.270 / 0.265**	

* p < 0.05 ** p < 0.01 *** p < 0.001.

Table C.3.1
Small regions weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable.

Predictor	Québec		Winnipeg		Hamilton	
	Coef.	CI	Coef.	CI	Coef.	CI
Intercept	10.30*	2.09–18.50	3.81	−4.86–12.49	3.97	−5.76–13.69
Socioeconomic characteristics						
Gender [Woman]	−0.35	−2.99–2.28	−0.08	−2.85–2.68	0.34	−2.74–3.42
Age	**−0.17*****	−0.26 to −0.08	−0.03	−0.12–0.06	**−0.16****	−0.26 to −0.05
Low-income household	1.97	−1.07–5.01	0.92	−2.21–4.05	1.03	−2.37–4.44
Household size	−0.56	−1.86–0.74	**−1.35***	−2.48 to −0.22	−0.21	−1.48–1.06
Full time empl.	**−8.78*****	−11.84 to −5.71	**−6.04*****	−9.13 to −2.95	**−9.45*****	−12.97 to −5.93
Travel and residential variables						
RSS near transit	**6.53*****	3.58–9.48	**3.18***	0.18–6.19	**5.93*****	2.57–9.28
Know how PT system work	0.05	−3.71–3.80	1.58	−2.42–5.58	**7.23*****	3.43–11.03
Ident: PT user and/or Ped.	**15.57*****	12.61–18.53	**15.30*****	12.07–18.53	**17.07*****	13.35–20.78
Perceived Accessibility						
By walking and/or PT to all destinations	**10.11*****	7.09–13.14	**6.31*****	3.42–9.20	**10.74*****	7.49–13.99
Calculated Accessibility by PT						
% of jobs access. by PT	**0.99*****	0.81–1.17	**0.57*****	0.44–0.70	**0.43*****	0.27–0.59
Observations	**1301**		**1183**		**993**	
R 2 / R 2 adjusted	**0.396 / 0.391**		**0.220 / 0.213**		**0.287 / 0.280**	

* p < 0.05 ** p < 0.01 *** p < 0.001

Table C.3.2
(continued) Small regions weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable.

Predictor	Halifax		Victoria		Saskatoon	
	Coef.	CI	Coef.	CI	Coef.	CI
Intercept	4.85	−4.20–13.91	−7.63	−17.31–2.04	−4.24	−12.12–3.64
Socioeconomic characteristics						

(*continued on next page*)

Table C.3.2 (*continued*)

	Halifax		Victoria		Saskatoon	
Predictor	Coef.	CI	Coef.	CI	Coef.	CI
Gender [Woman]	**−3.87****	−6.80 to −0.94	−1.91	−5.05–1.24	−1.73	−4.59–1.12
Age	−0.06	−0.16–0.03	0.02	−0.08–0.12	−0.02	−0.10–0.07
Low-income household	**4.46****	1.30–7.62	**4.25***	0.98–7.53	0.79	−2.28–3.87
Household size	0.31	−0.98–1.60	−0.42	−1.71–0.87	0.28	−0.96–1.52
Full time empl.	**−8.54*****	−11.82 to −5.27	−3.01	−6.55–0.53	0.09	−2.97–3.15
Travel and residential variables						
RSS near transit	**7.67*****	4.53–10.82	**8.55*****	5.15–11.94	**9.27*****	5.84–12.70
Know how PT system work	−1.62	−5.58–2.34	1.26	−3.17–5.68	1.98	−1.37–5.33
Ident: PT user and/or Ped.	**15.56*****	12.16–18.95	**20.82*****	17.01–24.63	**11.28*****	8.02–14.54
Perceived Accessibility						
By walking and/or PT to all destinations	**10.30*****	7.20–13.41	**13.83*****	10.59–17.07	**5.86****	2.84–8.87
Calculated Accessibility by PT						
% of jobs access. by PT	**0.55*****	0.44–0.65	**0.31*****	0.20–0.42	**0.46*****	0.34–0.59
Observations	**1100**		**1004**		**711**	
R 2 / R 2 adjusted	**0.349 / 0.344**		**0.311 / 0.304**		**0.252 / 0.241**	

* p < 0.05 ** p < 0.01 *** p < 0.001.

Appendix D. Appendix

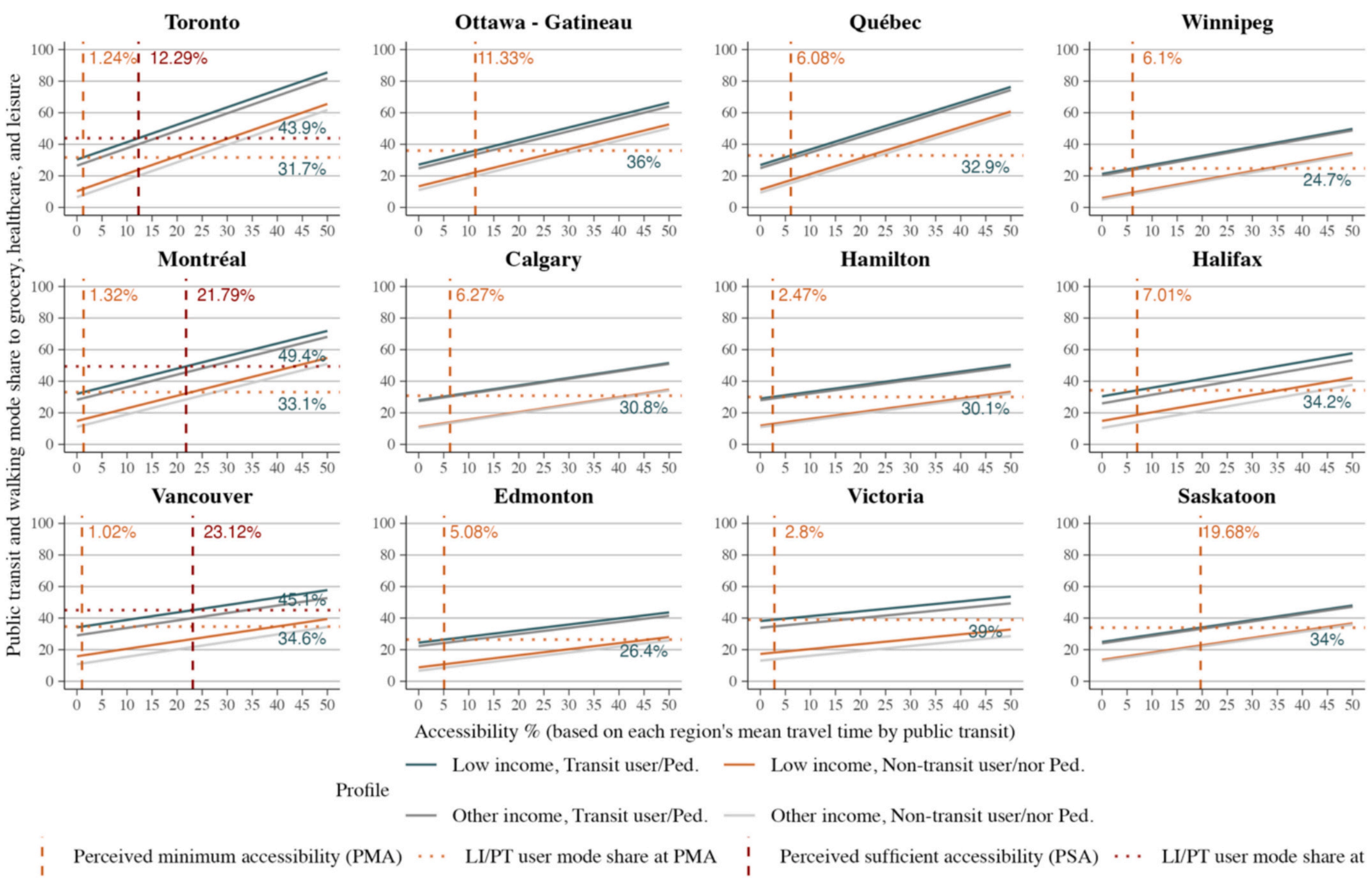

Fig. D.1. Marginal effects of accessibility on PT and walking mode share for multiple profiles, with reference lines showing the mode share at PMA and PSA for a low-income person who identify as a public transit user or pedestrian.

Data availability

The data that has been used is confidential.

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