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Exploring mobility of care with measures of accessibility

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Abstract:	Accessibility, the ease of interacting with potential opportunities, is an increasingly important tool amongst transport planners aiming to foster equitable and sustainable cities. However, in accessibility research there is a historical focus on employment destinations that is shaped by a masculinist transportation planning tradition. This paper aims to counter this gendered bias by connecting the Mobility of Care framework, a gender-aware transport planning conceptualisation to an empirical accessibility analysis of care destinations in the City of Hamilton, Canada. Care destinations are all the places one must visit to sustain household needs such shopping, errands, and caring for others (children and other dependents). Through the creation of a novel care destination dataset, this paper considers access to care across different modes of transport at two travel time thresholds (trips shorter than 15-minutes and 30-minutes). The methods include using a routinely used accessibility measure (cumulative opportunities) and a novel competitive and singly-constrained accessibility measure (spatial availability). Results indicate that accessibility to care destinations by car is exceptionally high, and access by public transit, cycling and by foot is low across the city with some exceptions in the inner city. Notably, there are distinctions between both methods: cumulative opportunities illustrate a more optimistic potential interaction landscape for non-car modes, while the spatial availability measure demonstrates a theoretically more realistic spatial distribution of care destination availability of potential interaction. Neighbourhoods with both low spatial availability to care and a high proportion of low-income households are also identified as areas in need of intervention. The manuscript and analysis is computationally reproducible and openly available. The analysis presented demonstrates methods planners can use to apply a gender-aware lens to accessibility analysis. Further, results can inform policies aiming to encourage sustainable mobility.
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Dear special issue editors Dr. Martínez-Díaz, Dr. Al Haddad, and Dr. Abouelela,

It is with great pleasure that I write to you, on behalf of myself and my co-authors, regarding our revised and resubmitted manuscript now titled: "Exploring mobility of care with measures of accessibility" to *Journal of Transport Geography*. We believe it is still a good fit for your special issue *Gender Gap in Mobility: Geographical Dimension and Implications* and its clarity has been especially improved in part because of the thoughtful comments provided by the reviewers.

As an overview of the changes made:

- The title of the manuscript has been changed from "Exploring mobility of care with measures of access: a case for gender-mainstreaming accessibility analysis", to "Exploring mobility of care with measures of accessibility".
    - The gender-mainstreaming perspective provided by Mobility of Care is now explained in text, therefore we were able to shorten the title to enhance clarity.
- The Introduction, Methods, and the Discussion and Conclusion sections now all mention the importance of considering low-income status in Mobility of Care research.
- The paper's objectives are more clearly stated.
- A short literature review section is added, following the Introduction section.
- Additional information regarding the transit, walk, and bike infrastructure in the case study is provided.
- Additional context on how care destination categories were decided on in the Destination Dataset subsection of the Background section is added.
- Additional justification for why the population data assumptions were made, in context to Mobility of Care, are added to the Background section in Population subsection.
- Clarified the flow of the manuscript by separating the Background from the Methods.
- Reshaped the writing in the Results section as well as the Discussion and Conclusions section with a focus on clarifying the paper's contributions, outlining limitations, and highlighting room for future work.

Thank you for considering our revised manuscript.

Regards,
The authors

Measuring mobility of care: an exploratory case of gender-mainstreaming accessibility analysis

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Conflicts of interest: None

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Conflicts of interest: None

Exploring mobility of care with measures of accessibility

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Abstract

Accessibility, the ease of interacting with potential opportunities, is an increasingly important tool amongst transport planners aiming to foster equitable and sustainable cities. However, in accessibility research there is a historical focus on employment destinations that is shaped by a masculinist transportation planning tradition. This paper aims to counter this gendered bias by connecting the Mobility of Care framework, a gender-aware transport planning conceptualisation to an empirical accessibility analysis of care destinations in the City of Hamilton, Canada. Care destinations are all the places one must visit to sustain household needs such shopping, errands, and caring for others (children and other dependents). Through the creation of a novel care destination dataset, this paper considers access to care across different modes of transport at two travel time thresholds (trips shorter than 15-minutes and 30-minutes). The methods include using a routinely used accessibility measure (cumulative opportunities) and a novel competitive and singly-constrained accessibility measure (spatial availability). Results indicate that accessibility to care destinations by car is exceptionally high, and access by public transit, cycling and by foot is low across the city with some exceptions in the inner city. Notably, there are distinctions between both methods: cumulative opportunities illustrate a more optimistic potential interaction landscape for non-car modes, while the spatial availability measure demonstrates a theoretically more realistic spatial distribution of care destination availability of potential interaction. Neighbourhoods with both low spatial availability to care and a high proportion of low-income households are also identified as areas in need of intervention. The manuscript and analysis is computationally reproducible and openly available. The analysis presented demonstrates methods planners can use to apply a gender-aware lens to accessibility analysis. Further, results can inform policies aiming to encourage sustainable mobility.

Keywords: Accessibility, Mobility of Care, Gender, cumulative opportunities, Spatial Availability

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1. Introduction

A gender bias exists in transport research and policy (Sánchez de Madariaga, 2013; Law, 1999; Siemiatycki et al., 2020). The field has historically focused predominately on the on-peak commute to work. While most women participate in the labour force, the commute is still a travel pattern more frequent among men (Sánchez de Madariaga, 2013). Women, on the other hand, have been found to complete more household-serving travel than men, such as escorting children (Craig and van Tienoven, 2019; Taylor et al., 2015; Han et al., 2019; McDonald, 2006), shopping, and errand trips (Taylor et al., 2015; Root et al., 2000; Sweet and Kanaroglou, 2016).

Although research on the gendered distribution of household-serving travel has existed for decades, it was Sánchez de Madariaga who introduced the "Mobility of Care" framework to support the proper accounting of travel needed to fulfill caring and home-related activities (e.g., the combined travel to grocery stores, errands, and picking-up or dropping off children) (Sánchez de Madariaga, 2013). Mobility of Care highlights how household-serving travel is systematically under-represented, under-counted, and rendered invisible in transport planning, particularly in travel surveys. Travel surveys are a key source of mobility data for transportation planners in metropolitan cities, and their primary focus is on the collection of 'compulsory' trip purposes such as school and work. In the Canadian context, respondents of the Transportation Tomorrow Survey (TTS) which encompasses the cities of Toronto, Hamilton and surrounding urban area (Data Management Group, 2018a), are given the following options to categorize their trip origins and destinations: home, work, school, daycare, facilitate passenger, marketing/shopping, other, or unknown. While home-work and home-school trips are easily identified, care trips are more challenging to discern. Likely, many shopping trips are for care purposes (e.g., groceries), but others may be for leisure. While escort trips may be well captured under the categories 'daycare' or 'facilitate passenger', trips to run errands or to attend health appointments may not be; it is probable that respondents categorize many of these trips as 'other' or even 'unknown'. Ultimately, the travel survey's focus is on a 'typical' trip to work or school (Data Management Group, 2018a); other trips are a by-product, minimialised in importance. Of course, people's travel behaviours are complex and surveys must balance detail with summary. However, what is seen as a 'typical' trip continues to shape transport and land-use, and this aggregation steers data-driven solutions from counted and observed home -work/-school based trips.

When travel surveys *are* designed to explicitly capture mobility of care, preliminary research has found that it comprises approximately one third of adults' trips (Gómez-Varo et al., 2023; Sánchez de Madariaga, 2013; Sánchez de Madariaga and Zucchini, 2019; Ravensbergen et al., 2022; Murillo-Munar et al., 2023). Given the large proportion of daily travel that mobility of care comprises, these trips should be explicitly captured in transport research. Further, the current under-reporting of mobility of care in research and planning has important equity considerations. Not only are mobility of care trips completed predominantly by women, this gendered discrepancy is greater in low-income households (Murillo-Munar et al., 2023; Sánchez de Madariaga, 2013; Ravensbergen et al., 2022). For instance, in lower income households in the city of Montréal, women complete 50% more care trips than men (Ravensbergen et al., 2022). The power of the Mobility of Care concept lies in its ability to highlight the masculinist bias in transport research – travel for care appears insignificant because travel surveys are not written to capture it (Sánchez de Madariaga, 2013).

Travel surveys, however, are but one source of information used by transport researchers and practitioners. Another popular instrument is accessibility, especially in the case of sustainable and equitable cities (Ryan et al., 2023; Bertolini et al.). Accessibility is an indicator of the ease of interacting with destinations. However, the point of interest in many accessibility-based assessments has been travel to work destinations by car or public transit modes e.g., (Kelobonye et al., 2019; Farber and Allen, 2019; Duarte et al., 2023; Ryan et al., 2023). Jobs are not always the most significant destination for many segments of the population. Further, modal options to employment and care trips differ. For example, women's commutes are on average a smaller proportion of their daily travel than men's (Ravensbergen et al., 2022). Care trips are also less likely to be completed by public transit or bicycle and are more likely done by car or by foot than the commute (Ravensbergen et al., 2022). One way to apply a gender-aware lens to accessibility analysis is by explicitly considering access to destinations involved in Mobility of Care by multiple modes. Reframing accessibility analysis in this way reinforces its importance as an instrument that supports the planning of sustainable and equitable travel and land-use in cities.

Taken together, this study's objective is to contribute to the transport planning literature through the demonstration of a multimodal accessibility analysis of Mobility of Care destinations. Two accessibility measures are used: the cumulative opportunities measure and the spatial availability measure. The measures are applied on a care destination dataset with novel Mobility of Care classifications for the city of Hamilton, Canada. The potential access to Mobility of Care destinations for walking, transit, bike, and on foot is calculated for 15- and 30-minute travel time thresholds. Results are compared across the two measures and four modes, and the overlap between low accessibility areas and high low-income prevalence is presented.

Implications of the results are discussed along with study conclusions.

2. Overview of multimodal accessibility analysis

As indicators of "the potential of opportunities for interaction" (Hansen, 1959), accessibility measures can also be interpreted as the relative ease of reaching destinations using transport networks: they are a byproduct of mobility and a representation of people's interaction with land-use and transportation systems (Hansen, 1959; Handy, 2020; El-Geneidy and Levinson, 2021).

The cumulative opportunities measure is a popular accessibility measure, widely appreciated for its intuitive computation (Handy, 2020; Handy and Niemeier, 1997; Kelobonye et al., 2019; Cheng et al., 2019). It quantifies how many destinations can be reached from a point in space within a given travel time threshold. The measure has been used to quantify access, given a travel time threshold and mode, often to employment destinations. Namely, access to employment is explored by car and/or transit (Kapatsila et al.; Deboosere and El-Geneidy; Tomasiello et al., 2023), by bike (Imani et al., 2019), and by foot (Singh and Sarkar, 2022). Non-work amenities have also been analysed by this popular measure. For example, grocery stores (Hosford et al.) and 'baskets' of urban-amenities (McCahill, 2018; Klumpenhouwer and Huang, 2021; Cheng et al., 2019). From the authors' review, the cumulative opportunities literature has not yet focused on destination selection from the lens of Mobility of Care.

A critique leveled at the cumulative opportunities measure (and other non-competitive accessibility measures) is its omission of competition-for-opportunities effects (Paez et al., 2019; Soukhov et al., 2023; Kelobonye et al., 2020; Merlin and Hu, 2017). Conceptually, this consideration is important as opportunities are finite, which leads to competition between the population seeking them. However, planners often opt for simpler measures (Kapatsila et al.) as measures that account for competition tend to be more difficult to implement and interpret (Merlin and Hu, 2017). In the recent work of Soukhov et al. (2023), an accessibility measure named Spatial Availability is introduced that simplifies the interpretation of resulting values while considering competition using a proportional allocation. It is extended for multimodal applications in Soukhov et al.. Notably, the use of competitive accessibility measures to explore access to a variety of destinations is scarce, with only recent exceptions (e.g., Kelobonye et al. (2020) and Singh and Sarkar (2022)). Moreover, competitive accessibility measures have yet to be focused on Mobility of Care destinations.

As presented in this work, two multimodal accessibility measures are implemented for the calculation of accessibility to Mobility of Care destinations. The first is a routinely used measure, the cumulative opportunities measure, and the second is a competitive and singly-constrained measure, spatial availability (Soukhov et al., 2023; Soukhov et al.).

3. Background on Hamilton

This paper focuses on Hamilton as a case study, a mid-size city of approximately 500,000 residents that lies within the urban and suburban Greater Toronto and Hamilton Area and is home to seven million people, or approximately 20% of the Canadian population (Toronto, 2022).

Hamilton is divided into six regional communities (Figure 1). Hamilton-Central is the most urbanized of the six, and the five periphery communities of Dundas, Ancaster, Flamborough, Glanbrook and Stoney Creek are significantly more suburbanized with the furthest periphery regions being undeveloped or rural owing to their inclusion in the region's greenbelt (Greenbelt Foundation, 2023). These different urban forms and associated transport infrastructure play a key role in access to care destinations. Hamilton Street Railway (HSR) is the city's transit provider operating only buses at the current date. Notably, Hamilton-Central is the only community fully serviced by HSR and has the highest concentration of walking and bike infrastructure for mainstream use (e.g., Level of Traffic Stress 1 or 2 which indicates low-speed, low-volume streets, separated bicycle facilities, and dedicated lanes where cyclist must interact with traffic at formal crossings (Conveyal)) as identified in the OpenStreetMaps road network (Geofabrik, 2023) and the city's General Transit Feed Specification file (Transit Feeds, 2023).

3.1. Care destination dataset

A novel geospatial dataset of care destinations for Hamilton was compiled using a variety of local sources and manually confirmed through Google Maps. As a way to showcase the dataset, it is grouped by care destination category. These five categories were generated by the authors following the travel purpose categories created in the mobility of care research by Sánchez de Madariaga and Zucchini (2019). Notably: child-centric (destinations for "Childcare" escorting trips), elder-centric (common destinations for other escorting trips that are not childcare-focused), grocery-centric, health-centric, and errand-centric destinations. The majority of destinations included can be publicly accessed (e.g., only public schools, grocery stores, clinics, community centres). However, certain destinations may require a fee that could be prohibitive for lower-income households (e.g., all long term care homes, both publicly subsided or private are included).

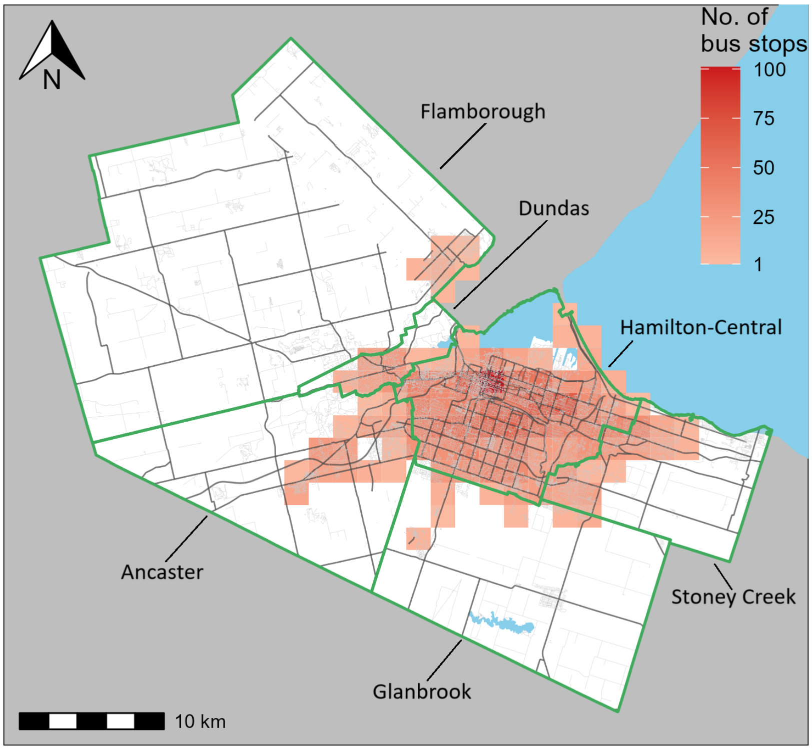

Figure 1: The six former muncipal boundaries in the city of Hamilton (green), highways and arerial roads (grey), walking and cycling infrastructure (light grey), and concentration of transit bus stops (reds). Geographic layer sources: road network (Geofabrik, 2023), transit stops (Transit Feeds, 2023), community boundaries (Hamilton, 2023) and lake (USGS, 2010).

Category sources of data and preparation notes are detailed in Table 1. Their spatial distribution and sub-categories are visualised in Figure 2.

Table 1: Details on the preparation and data sources of care destinations.

Care category	Sources	Data preparation notes
Child-centric	(Hamilton 2022a, 2023, 2022c, 2022d; Ontario 2023b)	Public schools, public and private (licensed) daycares, and public community centres, public recreation centres, and public parks: 1,190 locations are included. After manual review, all locations that typically do not serve children were removed including: Post-Secondary, Adult-Learning Centres, Group Homes, and Foster Care Centres. Further, through examination some Section 23 institutions defined as *"centres for children who cannot attend school to meet the needs of care or treatment, and rehabilitation"* (Ontario 2023a), were kept due to their innate connection to care.
Elder-centric	(Hamilton 2022d; Ontario GeoHub 2023)	Senior centres, long-term care homes, and retirement homes: 75 destinations are identified.
Grocery-centric	(Axle Data 2023)	Grocery stores, namely a place a household could buy groceries ranging from convenience stores to large retail stores: 381 destinations are identified. Data is filtered by Company Name, Suite Number, Address, City, Province, Phone Number and Postal Code. The type was then identified e.g., grocers specialty foods, grocers retail, grocer health food, grocer wholesale, grocer curbside, grocer delicatessen wholesale, grocer convenience. Data was crossreferenced to ensure all included locations were operational and legitimate grocery stores.

Care category	Sources	Data preparation notes
Health-centric	(Ontario GeoHub 2023; HNHB Healthline 2023)	Hospitals, pharmacies, clinics, and dentist offices: 421 destinations are identified. Hospitals and pharmacies were retrieved while clinics and dentistry clincs were manually scraped from a healthcare services database and checked via Google Maps to remove non-operational locations and confirm dentistry-orientation.
Errand-centric	Hamilton libraries (Hamilton 2022b), post office locations (Axle Data 2023; Canada Post 2023), and datasets of all national bank chains (BMO 2023; HSBC 2023; National Bank 2023; RBC 2023; Scotiabank 2023; TD Bank 2023).	Libraries, post offices, and banks: 158 destinations are identified. Post offices are retrieved from a mix of databases, and duplicates are removed. Banks are also derived from Data Axle and then cross-referenced to ensure data quality with a Bank Locator website for all national banking firms.

3.2. Population data

To supplement the care destination dataset and complete the accessibility calculation (discussed in the followng section), population data for the City of Hamilton is sourced from the 2021 Canadian census using the {cancensus} R Package (Statistics Canada, 2023a; von Bergmann et al., 2021). Three categories of variables are selected: the population, the percent of after-tax low-income-cut-off (LICO), and the primary commute mode used. LICO is a composite indicator included in the census that reflects the proportion of households spending 20% more than the area average on food, shelter and clothing (Statistics Canada, 2023b). As stated in the Introduction, women, especially those in low-income households, preform the majority of care trips. However, since the proportion of women and men residing across the city is balanced, this study focuses on the total population and total LICO prevalence. All data was sourced at the most granual level of spatial resolution publicly available, the level of the dissemination area (DA).

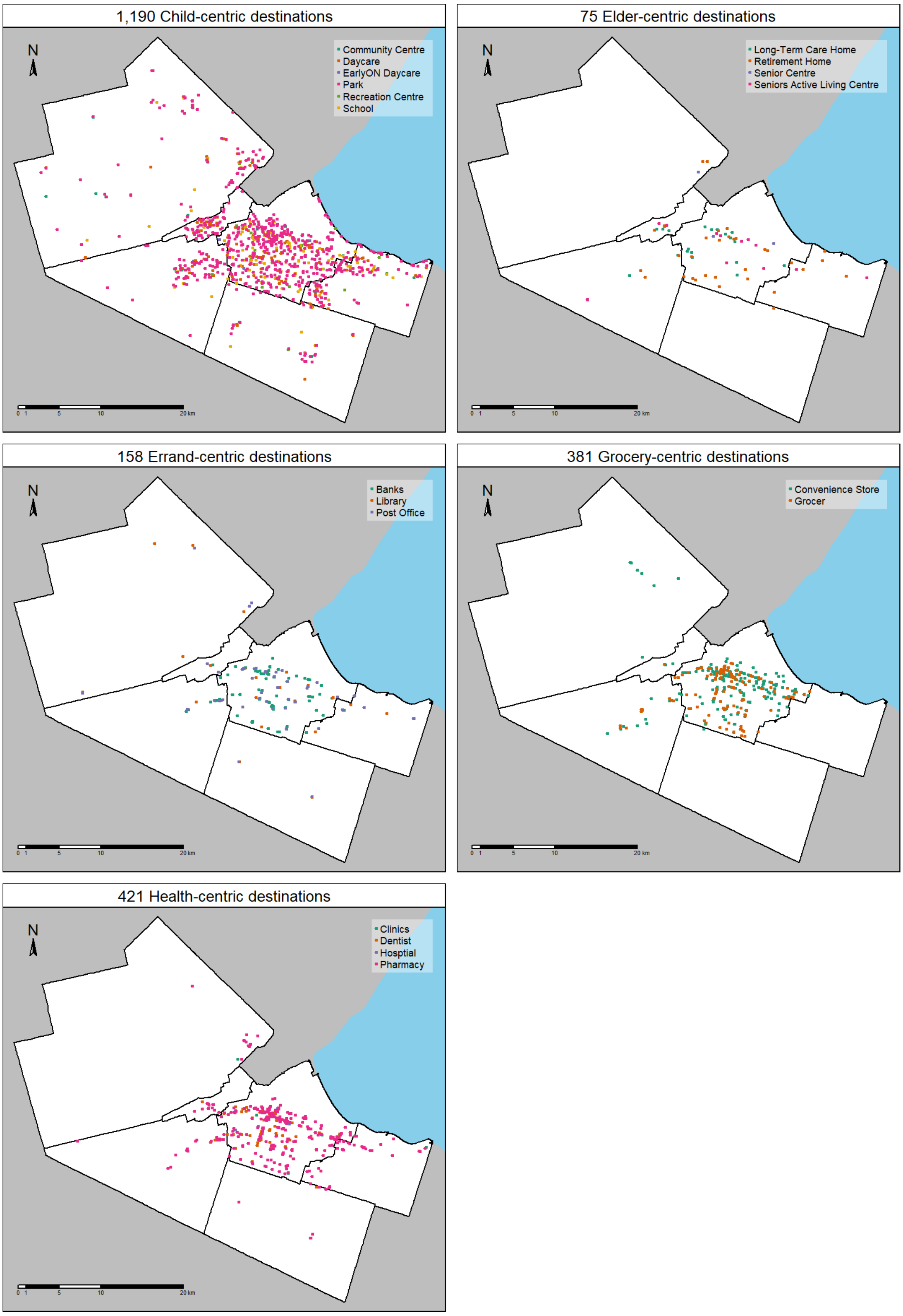

Figure 2: The geo-located points of care destinations in the City of Hamilton separated by the author-generated categories of: child-, elder-, errand-, grocery- and health- centric care categories. Locations of these destinations were retrieved through multiple sources as described in the text. Basemap shapefiles are sourced from the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

Figure 3 displays the spatial distribution of the total population and LICO prevalence as a percentage of the total population. Notably, the density of population within Hamilton-Central (oranges) and the cluster of high density and high LICO prevalence near the shoreline in Hamilton-Central (dark purple-oranges).

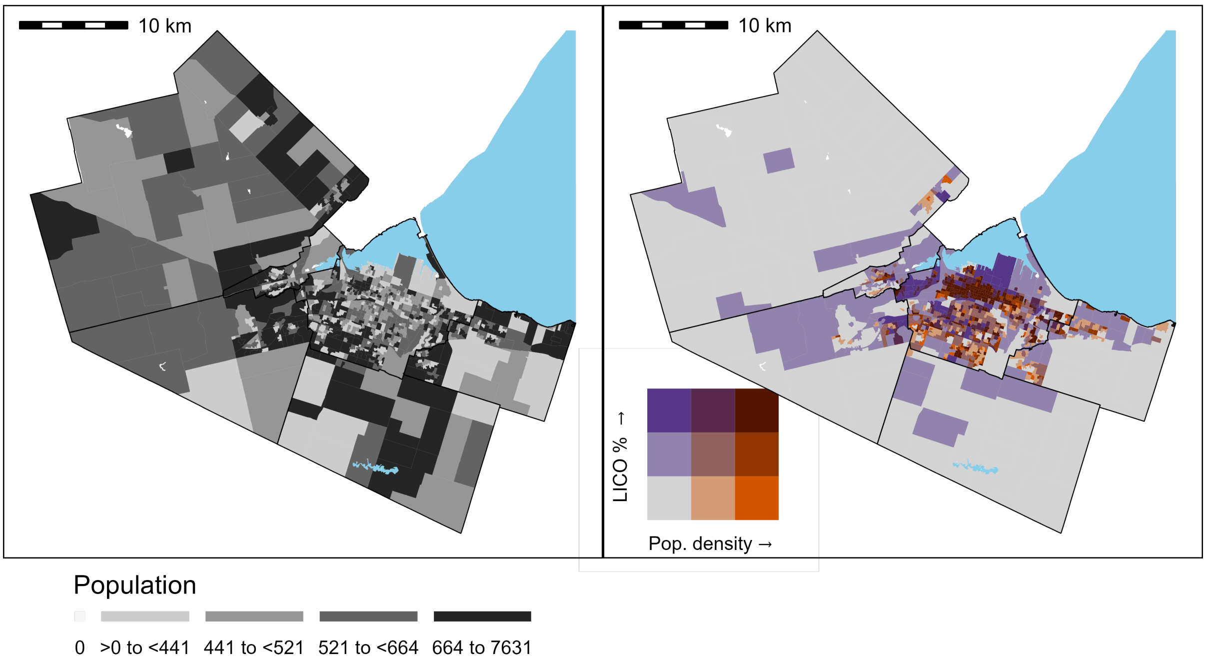

Figure 3: The total population in each dissemination area (DA) as provided in the 2021 Canadian census (Statistics Canada, 2023a), visualized within the six community boundaries in the city of Hamilton. The left plot represents the population and the right represents the population density versus the low-income cutt-off after taxes (LICO) as a percentage of the total DA population. LICO is a measure of economic disadvantage. The legend categories represent quartiles. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

Further, the population proportion that commutes by a specific mode (car, transit, walk, or cycle/other) is visualised in Figure 4. Though mode-choice used in travel to work is not necessarily reflective of the mode used to travel to care destinations, no other data is available at a granular level City-wide that centers mobility of care to our knowledge. The population generally commutes by car (50% or higher, is yellow to green), even within the more densely populated Hamilton-Central. However, for transit and walking, a group of DAs near the shoreline within Hamilton-Central have the highest proportion of transit users and those who walk to work (yellows in the plots that are otherwise red i.e., below 15%). Those same DAs are also relatively dense and have a high prevalence of LICO (Figure 3).

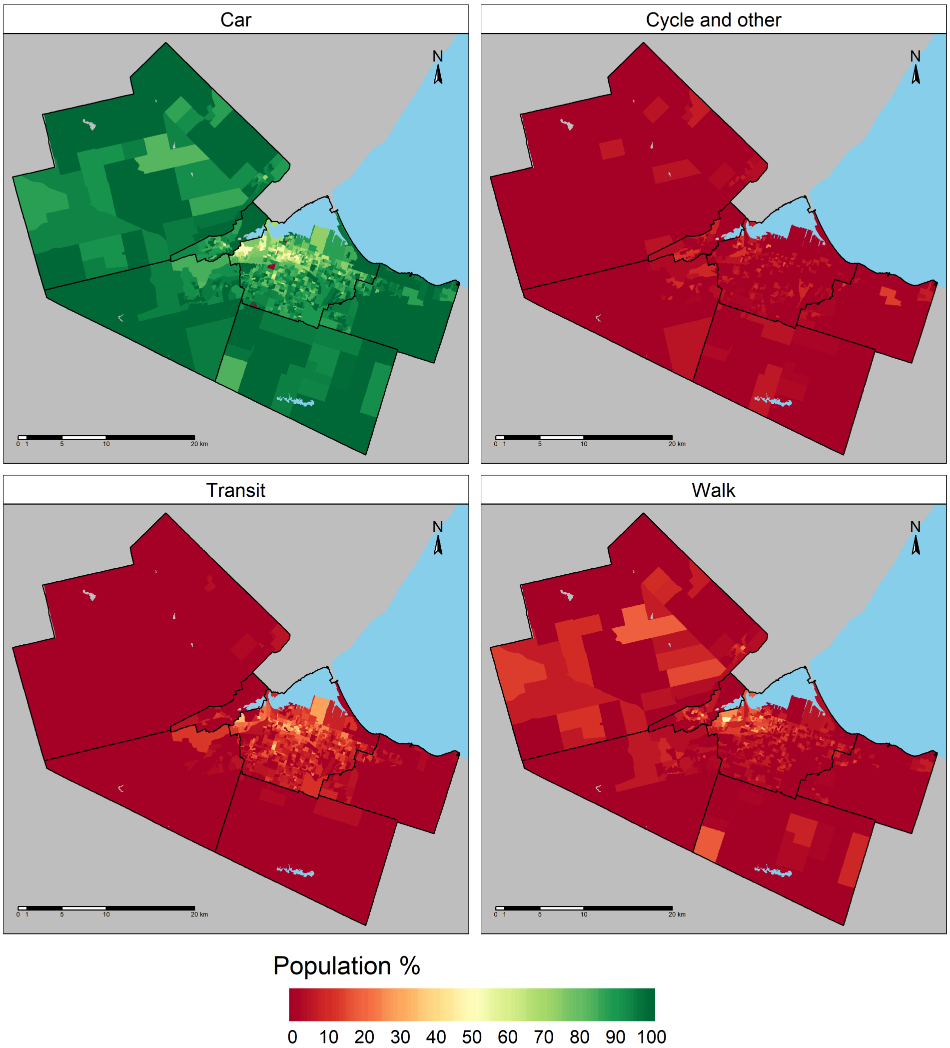

Figure 4: The proportion of mode type used for commuting (aged 15 and older employed in the labour force) in each dissemination area (DA) as provided by the 2021 Canadian census (Statistics Canada, 2023a). Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

3.3. Transportation network and travel time estimations

As empirical travel behaviour to care-oriented destinations is uncounted and thus travel time is unavailable, travel time is approximated. Travel times by walking, cycling, transit and car is calculated for the geometric centroids of the DAs to the geometric centroids of the care destination location using the 'travel_time_matrix()' function from the {r5r} package (Pereira et al., 2021). Inputs are point locations of DA centroids (origins), care destinations centroids, an OpenStreetMap road network including bike, transit and vehicle infrastructure (Geofabrik, 2023), and city GTFS transit routes/schedules (Transit Feeds, 2023). For all modes, travel times under 60 minutes based on the shortest travel-time path are calculated.

For transit and cycling, additional parameters were included. For transit travel times, a Wednesday departure time of 8:00AM was selected (Boisjoly and El-Geneidy, 2016) with a departure travel window parameter of 30 mins. Travel times are calculated for each minute of the travel window (8:00-8:30AM) and the 25th percentile from the distribution of travel window times were selected to represent each origin-destination. Selecting a sufficiently wide window is an important consideration as travel times are sensitive to transit vehicle frequency and connecting transfers (see discussion of the modifiable temporal unit problem e.g., (Pereira, 2019)). The 25th percentile indicates that 25% of trips from that origin to destination have a travel time that is that length or shorter. This assumption provides an optimistic perspective of transit travel times. For cycling travel times, level 1 or 2 traffic level of stress routes (i.e., dedicated or separated cycling lanes respectively) were selected. The level of traffic stress is a variable associated with links of the OSM road network; level 1 and 2 are considered the default.

4. Accessibility measurement methods

Two accessibility measures are detailed: the cumulative opportunities measure and the spatial availability measure. Both yield a value per spatial unit that represents how many care destinations can be reached within a given travel time, for a given mode. However, both measures have different underlying assumptions; the first does not consider competition effects and the second does.

4.1. Cumulative opportunities: the number of care opportunities that can be reached by a mode within a travel time

Often referred to as the cumulative opportunities measure, it is a special form of the gravity-based accessibility measure used in at least as far back as Hansen (1959; Handy and Niemeier, 1997). Its name is drawn from its' interpretation: the value calculated for each spatial unit (DAs in this study) represents the number of opportunities that can be spatially accessed within a given travel time. The cumulative opportunities accessibility measure takes the following general form for a multimodal calculation:

$$S_i^m = \sum_j O_j \cdot f^m(c_{ij}^m)$$

Where:

- i is a set of origin locations (e.g., DA centroids)
- j is a set of destination locations (e.g., care destinations)
- m is a set of modes (e.g., by foot, cycle, transit and car)
- O_j is the number of opportunities at j (e.g., the presence of a care destination in this study)
- c_{ij}^m is the travel cost between i and j for each m.
- $f^m(\cdot)$ is an impedance function of c_{ij}^m for each m; within the cumulative opportunities measure, it is a binary function that takes the value of 1 if c_{ij}^m is less than a selected value.
- S_i^m is the cumulative opportunities accessible by m at each i.

4.2. Spatial availability: the number of care opportunities that are spatially available to a mode-user within a travel time

Differing from cumulative opportunities measure, the spatial availability measure considers competition leading to a different interpretation in its results. The values for each origin i (in our study, DAs) for a given mode m represents the number of care opportunities that can be accessed by a mode-user out of *all* care opportunities in Hamilton. Spatial availability considers competition through proportional allocation of opportunities to a given i based on the relative proportion of population computing for an opportunity and their travel times. Each V_i value represents the potential availability of reachable destinations. Spatial availability, takes the following general form for multimodal calculation:

$$V_i^m = \sum_j O_j \; F_{ij}^{tm}$$

Where:

- Like in Equation (1), i, j, and m is a set of origin locations, destination locations, modes respectively and O_j is the number of opportunities at j.

- V_i^m is the cumulative opportunities spatially available by m-using population at i for each i.
- F_{ij}^{tm} is a total balancing factor for each m at each i; it considers the size of the populations at different locations that demand opportunities O_j, as well as the cost of movement in the system $f(c_{ij})$.

What makes spatial availability stand apart from other competitive measures is the multimodal balancing factor F_{ij}^{tm} (Soukhov et al., 2023). F_{ij}^{tm} implements a proportional allocation mechanism that ensures the sum of all spatial availability values V_i^m across all modes m in the region always matches the total number of opportunities (i.e., $\sum_j O_j = \sum_i V_i = \sum_m \sum_i V_i^m$). This constraint helps in clarifying the interpretation of the V_i^m value itself.

The total proportional allocation factor F_{ij}^{tm} consists of two parts: the first is a population-based proportional allocation factor F_i^{pm} that models the mass effect (relative population-demand for opportunities) and the second is an impedance-based proportional allocation factor F_{ij}^{cm} that models the cost effect (relative travel time). Both factors consider competition through proportional allocation: F_i^{pm} estimates a proportion of how many people are in each i and using each m relative to the region and F_{ij}^{cm} estimates a proportion of the cost of travel from i to j at each i using each m relative to the region. Since F_i^{pm} and F_i^{mc} are proportions, $\sum_m \sum_i F_i^{pm} = 1$ and $\sum_m \sum_i F_i^{cm} = 1$. Both factors are combined to create the total balancing factor F_{ij}^{tm} used to calculate V_i^m:

$$F_{ij}^{tm} = \frac{F_i^{pm} \cdot F_{ij}^{cm}}{\sum_m \sum_i F_i^{pm} \cdot F_{ij}^{cm}}$$

Where:

- The factor for allocation by population for each m at each i is $F_i^{pm} = \frac{P_i^m}{\sum_m \sum_i P_i^m}$. This factor makes opportunities available based on demand.
- The factor for allocation by cost of travel for each m at i is $F_{ij}^{cm} = \frac{f^m(c_{ij}^m)}{\sum_m \sum_i f^m(c_{ij}^m)}$. This factor makes opportunities available preferentially to those who can reach them at a lower cost.

4.3. Travel impedance function selection

A binary travel impedance function $f^m(c_{ij}^m)$ is assumed (e.g., c_{ij} is equal or below a certain travel time threshold, $f^m(c_{ij}^m)$ equals 1, otherwise, $f^m(c_{ij}^m)$ equals 0). Two travel time thresholds are selected for both measures: 15 minutes and 30 minutes for all modes.

This selection is informed by a scan of the literature. Typically, literature considers travel to one type of care category (e.g., health, or school, or grocery stores) and each destination type is associated with different travel impedance behaviour (e.g., grocery shopping trips are on average 15 minutes (Hamrick and Hopkins, 2012), trips to receive cancer treatments are on average 20 minutes (Segel and Lengerich, 2020)). In other care-related accessibility analyses, travel time thresholds of include 10 mins (for daycares) (Fransen et al., 2015) and 30 mins to 1 hr (for hospitals) (Schuurman et al., 2006) are selected. Of the one study to-date that has calculated the average travel times to all different categories of care destinations, travel times to each care category differ by mode e.g., 16 minutes by car and 36 minutes by public transport (Ravensbergen et al., 2022). To broadly reflect this past research: 15 and 30 minutes are selected for all modes.

Notably, the use of a binary travel impedance functions as opposed to a distance-decay impedance function, were selected to simplify communication of the assumed travel behaviour. As mentioned, lacking region-specific empirical data regarding care-centric travel, this work establishes a methodology to streamline access to care interpretation and analysis for when that data is available.

5. Results

5.1. Spatial access to care opportunities

The cumulative opportunities and spatial availability plots for each mode, for both 15-minute and 30-minute travel time thresholds are shown in Figure 5. Each cumulative opportunities value represents a cumulative count of care opportunities that can be spatially accessed by each mode from each DA, where each opportunity represents a reachable care destination. In this case study, the spatial availability measure presents a constrained interpretation of this measure; each value is a cumulative count of care opportunities that can be spatially accessed from each DA *and are spatially available to the mode-using population based on the relative size of the mode-using population and modal travel times.* As proportional allocation is used, each spatial availability value can also be interpreted as the *spatially available* proportion of the total care destinations in the city, i.e., the sum of all spatial availability values in the second row of Figure 5 equal 2,225, the total number of care destinations in this case study.

In both measures, the higher the value, the more potential interaction with care opportunities. This greater potential of opportunity of interaction is conceptualised as a positive outcomes of well functioning land-use and transport networks (Cordera et al., 2019; Blumenberg and Pierce, 2017; Cui et al., 2020). In Figure 5, values are grouped by quantile and spatial trends between the 15-min and 30-min threshold plots are highly correlated (0.92 for cumulative opportunities and for 0.89spatial availability).

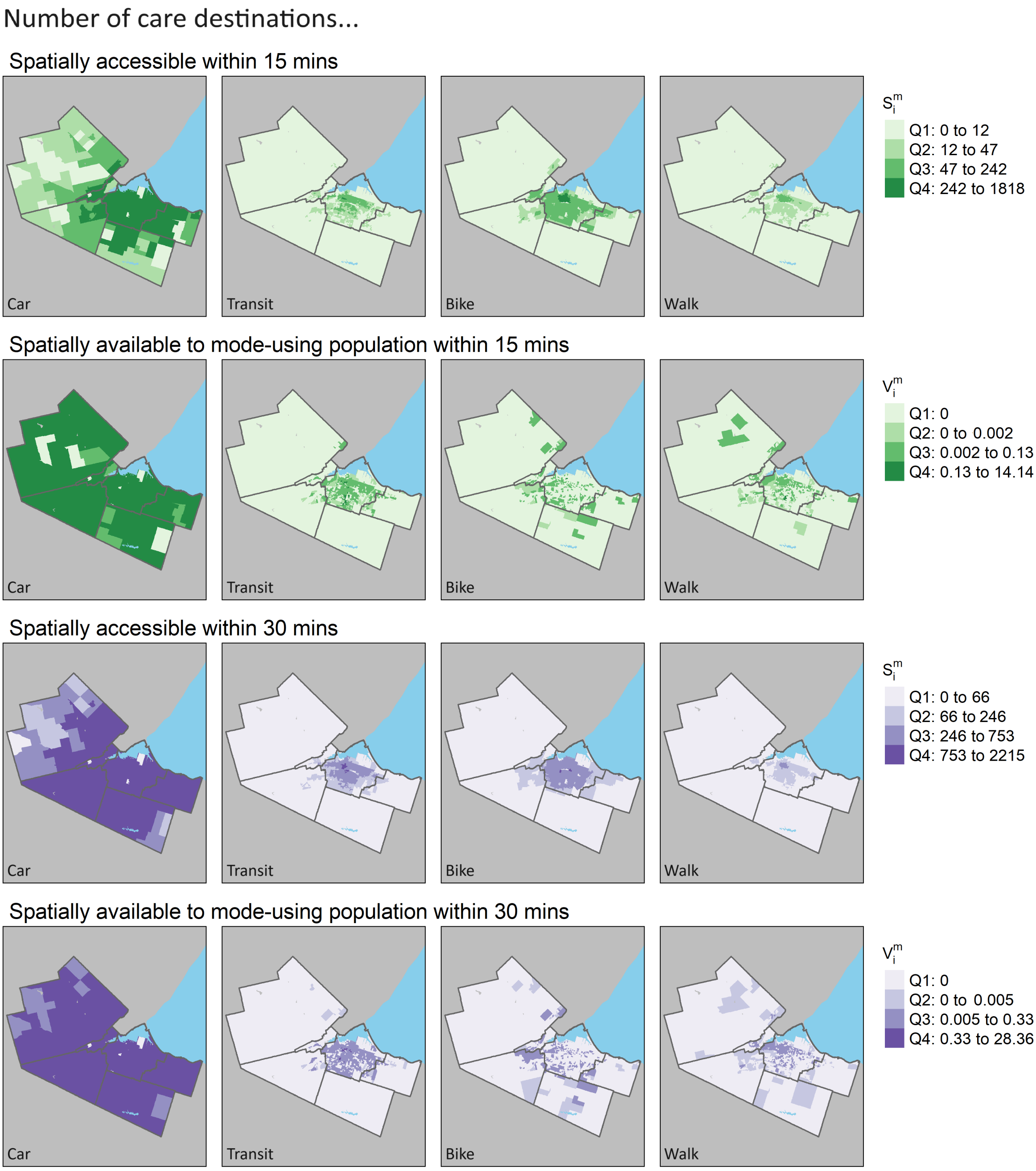

Figure 5: The number of care destinations that can be reached, per DA, within 15 mins (top) and 30 mins (bottom) for the cumulative opportunities and spatial availability measures. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

When considering the cumulative opportunities measure; three notable findings between modes can be identified. First, access by transit and walking is somewhat high (mostly Q3 and some Q4) within the core of Hamilton-Central but low elsewhere. This finding is somewhat expected as as transit does not significantly serve communities outside of Hamilton-Central and Dundas and the density of walking infrastructure is high in Hamilton-Central (see Figure 1). Second, access by cycling is even higher (mostly Q3 but more Q4) in Hamilton-Central; it provides the second most opportunities for interactions after travel by car, and affords at least one opportunity for interaction in more DAs than walking and transit use (notably some access (Q1) in rural communities). Third, the access that the car-mode provides is significantly higher relative to the three sustainable modes. Travel by car results in the greatest maximum number of potential interactions to care destinations (1818 and 2215 opportunities within 15-min and 30-mins respectively). Car-mode offering high accessibility to care destinations is an expected outcome given the car-oriented design of North American cities (Saeidizand et al., 2022) and the range (travel speeds over a distance) of the car mode. However, though car ownership is high in Hamilton, not everyone has access to a private vehicle. For instance, 13% of Hamilton households own zero vehicles (Data Management Group, 2018b), presenting equity concerns in who may benefit from the high accessibility car-mode offers. The cumulative opportunities access is insightful in illustrating the range in which opportunities can be accessed by each mode based on their travel speed (on available infrastructure); a summary of each origins' modal opportunity isochrone. However, the cumulative opportunities measure does not account for competition effects. Namely, what proportion of the modal opportunity range is *spatially available* to a mode-user at a given location when competing for those same opportunities with other mode-users. Considering competition in this way conjures richer conclusions that reflects the mode-using population. For instance, consider cycling, a mode that offers a relatively high range but still smaller than the car. The cumulative opportunities values in Figure 5 reflects this intuition: Q3 and Q4 cumulative opportunities values are present for cycling in Hamilton-Central, offering the second best cumulative opportunities after the car. However, bike spatial availability values depicts a more complex story of opportunity accessibility: it reflect the mode's opportunity range as well as proportion of mode-using population and how their range relatively compares to all other modes. The bike-using population is small (2% of the population), with many DAs having no or low proportions of bike-users. Meaning DAs with no bike-users are proportionally allocated no access to opportunities (zero spatial availability) and DAs with a small proportion of cyclists have relatively slow travel speeds compared to the car-using population. Though bike mode offers a relatively high opportunity range (cumulative opportunities), because of the low proportion of cyclist and their opportunity range compared to the *many* other mode-users, they receive low spatial availability values.

In the case study, spatial availability values reflect the proportion of cumulative opportunities accessibility to the mode user (based on relative population and travel times), which can be used to shed light on what mode, and in what region, a mode-using population captures more than its equal share of spatial availability. Overall, 98% of the spatial availability is taken by motorists (destinations within 30-minutes) but they only represent 87% of the population. Therefore, they have disproportionately more availability than their population's presence in the city. Motorists capture this availability from populations that do not use cars, and as a result are left with lower spatial availability. For instance, transit users that have access to destinations within 30-minutes represent 7% of the population but claim only 2% of the spatial availability. Similarly, though cyclists and pedestrians represent 2% and 4%of the population respectively, they only capture 0.3% (cyclist) and 0.3% (pedestrian) of the spatial availability. In other words, if certain mode-users capture a greater proportion of spatial availability, then there is less spatial availability remaining for other mode users. Spatial availability does not necessarily have to align with the cumulative opportunities that the mode offers, it is simply a constrained version that considers competition by mode-using populations. As noted, non-car modes have the potential to offer higher cumulative opportunities (within Hamilton-Central), but as it exists assuming modal commute shares, the majority of spatial availability to care destinations can still be captured by motorists even in DAs where car mode share is under 50% (such as Hamilton-Central, see proportions in Figure 4).

Taken together, though non-car modes may provide somewhat good access to care destinations within Hamilton-Central (and some only some access in rural communities), they do not provide similar levels of spatial availability. Car-using populations capture more spatial availability, even in the centre of Hamilton-Central, than all other modes. Note the lower number of Q3 and Q4 values within and radiating outwards from Hamilton-Central for non-car modes for cumulative opportunities measure compared to spatial availability. This indicates that cumulative opportunities measures may overestimate the access to care destinations that non-car modes (pedestrians, cyclists, and transit users) have available to them.

5.2. Spatial availability and low-income mismatch

To draw insights on who may reside in DAs where populations are disadvantaged with low modal spatial availability and high low-income prevalence, a cross-tabulation is visualised in Figure 6. The modal spatial availability is divided by the mode-using population in each DA, resulting in the rate of modal spatial availability. LICO prevalence is the proportion of population that falls below the low-income cuttoff threshold (see Figure 3). Figure 6 can be interpreted as follows: residents who use a specific mode in a "yellow" DA reside in a DA that offers below average spatial availability (i.e., below or equal to the the 50th percentile (median) levels of spatial availability per mode-using population) and the population within the DA has a high LICO-prevalence (i.e, 80th percentile or higher (8.4% or more)).

Notice the green DAs for the car-driving population and presence of yellow DAs for non-car modes within Hamilton-Central: Figure 6 reinforces findings from Figure 5. Even in Hamilton-Central where there is high proportion of LICO prevalence, car-mode using populations who reside in green DAs are still offered high levels of spatial availability. However, car ownership is not always possible for low-income households and the lack of ownership acts as a barrier to accessing economic and economic-support opportunities for low-income households (Morris et al., 2020) when alternative modes are insufficient (Klein et al., 2023). For this reason, populations below the LICO may rely on non-car modes, and the introduction of policies that increase access to care-destinations could be considered. The majority of yellow DAs are within the centre of Hamilton-Central, specifically for cycle- and walking populations. Policies that increase the number of available care-destinations within Hamilton-Central, improve conditions that decrease LICO-AT prevalence, as well as policies that make car-modes less spatial availability advantaged (i.e., encourage modal shift and decrease travel time) could be further investigated through the lens of mobility of care.

6. Discussion and conclusions

This paper is the first to conduct an exploratory multimodal accessibility analysis of Mobility of Care destinations – one that counters the current literature's emphasis on employment-related destinations, a travel purpose more significant for men, and especially wealthy and educated men (Law, 1999; Hanson, 2010). Its aim is to challenge current planning paradigms by explicitly focusing on care destinations, locations that are vital for life-sustaining activities that are currently undervalued. This study also provides a tangible example of how one could conduct gender-aware multimodal accessibility analyses using the City of Hamilton as a case study. In doing so, this paper contributes to the emergent mobility of care literature, a body of what that has, to date, focused on quantifying this under-represented type of travel (Gómez-Varo et al., 2023; Murillo-Munar et al., 2023; Ravensbergen et al., 2022; Sánchez de Madariaga, 2013; Sánchez de Madariaga and Zucchini, 2019; Shuman et al., 2023) and providing rich and nuanced qualitative accounts of lived experiences completing mobility of care (Orjuela and Schwanen, 2023; Ravensbergen et al., 2020; Sersli et al., 2020).

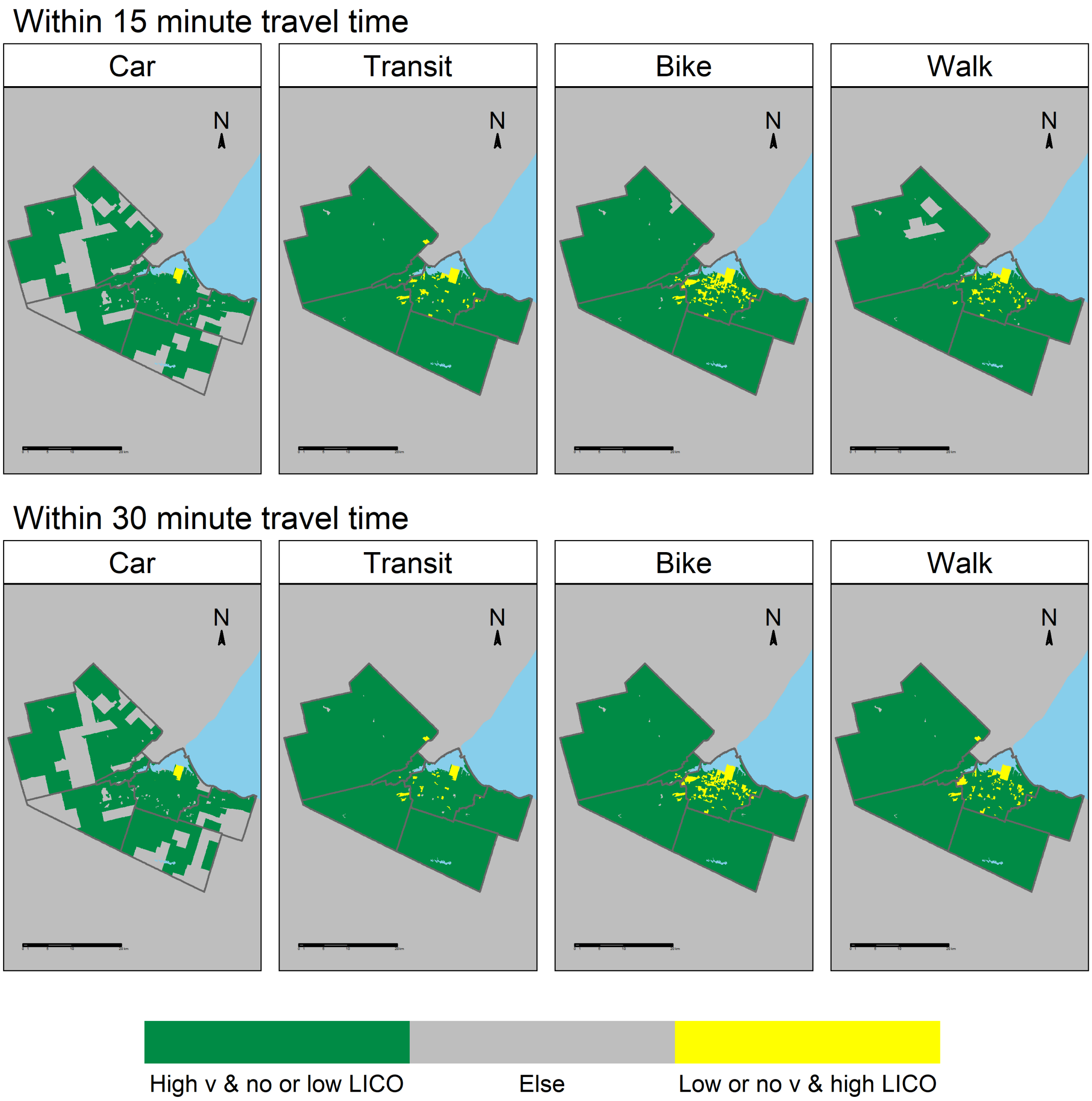

Figure 6: The spatial availability per mode-using-capita measure versus LICO prevelance, visualized for 15 mins (top) and 30 mins (bottom) travel time cutoffs. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

This study also methodologically contributes to the accessibility literature by contrasting two multimodal accessibility measures: the widely used cumulative opportunities measure and the spatial availability measure, which offers accessibility insights on modal competition. The cumulative opportunities measure demonstrates the modal range of access by presenting the number of care destinations that each mode can reach within a 15- and 30- minute travel time threshold from each spatial location. Spatial availability constrains the cumulative opportunities measure by incorporating the *assumed* proportions of mode-using populations and mode-specific travel times; this yields the number of care destinations that the mode-using population has access to out of all care destinations in the study region. The two measures communicate different insights about the case study: the study's results demonstrate that the car mode offers high cumulative opportunities access as well as exceptionally high spatial availability for motorists. While sustainable modes offer lower cumulative opportunities access (though higher in the city center) and, in certain areas, even lower spatial availability due to the disproportionately high spatial availability for the car users. In this way, relying only on the cumulative opportunities measure provides an incomplete picture, as it does not reflect how the relatively large quantity of motorists and the greater range offered by the car can disproportionately claim more care destinations than non-car modes (pedestrians, cyclists, and transit) users. Although spatial availability offers a more complex picture of how modes provide access under competition, spatial availability like other competitive measures, relies on assumptions about who is "demanding" destinations and by how much. How those assumptions are made are a subject of ongoing discussion in the competitive accessibility literature (Merlin and Hu, 2017; Kelobonye et al., 2020).

Further, this study contributes to the literature on equitable and sustainable transportation planning by providing a methodology to identify areas in need for further development. By highlighting how the car offers all-round high access and even higher spatial availability to care destinations in Hamilton, sustainable modes can be prioritized equitably. Previous research suggests that currently care trips are more frequently completed by car than by transit or bicycle (Ravensbergen et al., 2022) as they often involve carrying things (e.g., groceries) or people (e.g., children). Qualitative work supports this preference, citing convenience and increased safety as key reasons for choosing travel by car for care trips (Maciejewska and Miralles-Guasch, 2019; Carver et al., 2013).

However, this study also highlights that the high spatial availability of motorists results in disproportionately low spatial availability for sustainable mode users, even in Hamilton-Central. While sustainability policies should aim to re-balance the spatial availability away from motorists to users of sustainable modes, these policies should incorporate an equity perspective that considers existing preferences in care trips. This study provides the stepping stones for such an equity lens in Figure 6, by presenting a cross-tabulation of areas with high LICO prevalence and low spatial availability per sustainable-mode that could be the focus of policy intervention. Consider the cycling plot in Figure 6, a factor driving the higher quantity of yellow DAs is the low proportion of cyclists assumed. This assumption holds in other Canadian contexts, cycling as a mode for care trips is also uncommon as cycling is uncommon (Ravensbergen et al., 2022). Moreover, as care trips tend to be preformed by women, the low proportion of cycling for care trips has been put forth as a hypothesis to explain the gender-gap in cycling observed in low-cycling cities (like Hamilton) where only a third of cyclists are women (Ravensbergen et al.; Prati, 2018). However, cycling as a mode has potential as it demonstrates high cumulative opportunities values. However, that potential is not being realized in part due to the low proportion of cyclists and the higher spatial availability values of motorists. Future research could examine what barriers those who conduct care trips are facing in regards to cycling, particularly focusing on the yellow areas indicated Figure 6.

6.1. Study limitations

This study presents three types of limitations related to assumptions in the accessibility measure methods and data availability. First, since travel times from origin to care destination are unknown, they are estimated assuming a road network under free-flow conditions. While this affects the estimated travel times, research suggest that considering congested conditions may not significantly impact the resulting accessibility values (Yiannakoulias et al., 2013). In the context of Hamilton, congestion is also pertinent to car and transit modes, and not for pedestrians or cyclists (their travel infrastructure). Second, using a binary impedance function instead of a more complex distance-decay function could significantly affect accessibility results (Kapatsila et al.). For instance, destinations beyond a 30-minute travel time could still be valued by people, and those within 5 and 15 minutes do not necessarily have the same importance. However, the use of the binary impedance function trades complexity for interpretation, and this trade-off was made strategically made to improve interpretability and compare the two accessibility measures. To enhance reliability, two literature-informed travel cost thresholds (15-minutes and 30-minutes) are selected. Third, the geometric centroids of DAs (origins) and destinations (all care destinations) were used as inputs for travel time calculations. This is a limitation as DAs were created for the purpose of the statistic census: they vary in area and their centroids may not necessarily align with where that population may begin their journey to care destinations. This methodological decision presents limitations on how the travel time estimates can be interpreted to reflect actual travel times to care destinations.

Moreover, due to the exploratory nature of this research and novelty of the Mobility of Care concept, no research to date has directly captured the characteristics of mobility of care trips in Hamilton. The presented results thus are not calibrated to reflect observed mobility of care travel behaviour nor establish normative accessibility goals (Páez et al.). Travel behaviour data is needed to calibrate local destination-specific travel impedance cutoffs (e.g., using a 15 minute cutoff for grocery-centric destinations and 30 minute cutoff for health-centric destinations) or assigning weights for each destination type as done in previous studies (e.g., a weight that reflects their 'capacity' (Li and Wang, 2024) or their 'attractiveness' using origin-destination flows from travel surveys (Graells-Garrido et al., 2021; Cheng et al., 2019)). In absence of travel behaviour data, this study uses uniform travel time thresholds for all destinations and no destination weights are applied. This limits the result's interpretation to the *potential* to access *all* care destinations within 15- or 30- minutes, it does not include the real individual socio-economic and intersectional characteristics that influence what destinations can be potentially accessed. Consequently, each destination is treated as a single opportunity, e.g., a school, a clinic, a hospital, and a grocery store are all equal to one opportunity each. Additionally, since care trip modal choice is unavailable at a disaggregated level for Hamilton, the commute mode choice is assumed for the spatial availability measure. This mode may not be what is used to visit care destinations and hence places an limitation on how the results should be interpreted.

Taken together, the discussion of these limitations present room for future research to incorporate context-specific mobility of care travel surveys into accessibility analysis to more accurately reflect mobility of care accessibility landscapes. Future work could also look to disaggregate access to care by category and compare results to conventional access to work landscapes. This comparison could highlight the bias in planning towards jobs as well as substantiate equity critiques.

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Exploring mobility of care with measures of ~~access: a case for gender-mainstreaming~~ accessibility~~analysis~~

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Abstract

Accessibility, the ease of interacting with potential opportunities, is an increasingly important tool amongst transport planners aiming to foster equitable and sustainable cities. However, in accessibility research there is a ~~masculinist bias whereby employment destinations are often the default~~historical focus on employment destinations that is shaped by a masculinist transportation planning tradition. This paper aims to counter this gendered bias by connecting the Mobility of Care framework, a gender-aware transport planning conceptualisation to an empirical accessibility analysis of care destinations in the City of Hamilton, Canada. Care destinations are all the places one must visit to sustain household needs such shopping, errands, and caring for others (children and other dependents). Through the creation of a novel care destination dataset, this paper considers access to care across different modes of transport at two travel time thresholds (trips shorter than 15-minutes and 30-minutes)~~using unconstrained (cumulative opportunity) and competitive-constrained~~. The methods include using a routinely used accessibility measure (cumulative opportunities) and a novel competitive and singly-constrained accessibility measure (spatial availability)~~measures. Results generally indicate that travel~~. Results indicate that accessibility to care destinations by car is exceptionally high, and access by public transit, cycling and by foot is low across the city with some exceptions in the inner city. ~~Noteably~~Notably, there are distinctions between both methods: ~~unconstrained access illustrates~~ cumulative opportunities illustrate a more optimistic potential interaction landscape for non-car modes, while ~~competitive and constrained access demonstrates a conceptually~~ the spatial availability measure demonstrates a theoretically more realistic spatial distribution of care destination availability of potential interaction. Neighbourhoods with both low spatial availability to care and a high proportion of low-income households are also identified as areas in need of intervention. The manuscript and analysis is computationally reproducible and openly available. The analysis presented demonstrates methods planners can use to ~~gender-mainstream~~ apply a gender-aware lens to accessibility analysis. Further, results can inform policies aiming to encourage sustainable mobility.

Keywords: Accessibility, Mobility of Care, Gender, ~~Cumulative Opportunity~~ cumulative opportunities ,

1. Introduction

A gender bias exists in transport research and policy (Sánchez de Madariaga, 2013; Law, 1999; Siemiatycki et al., 2020). The field has historically focused ~~on one trip purpose;~~ predominately on the on-peak commute to work. While ~~many women do, of course, work,~~ most women participate in the labour force, the commute is still a travel pattern more frequent ~~amongst~~ among men (Sánchez de Madariaga, 2013). Women, on the other hand, have been found to complete more household-serving travel than men, such as escorting children (Craig and van Tienoven, 2019; Taylor et al., 2015; Han et al., 2019; McDonald, 2006), shopping, and errand trips (Taylor et al., 2015; Root et al., 2000; Sweet and Kanaroglou, 2016).

~~Though~~ Although research on the gendered distribution of household-serving travel has existed for decades, it was ~~only in 2013 that~~ Sánchez de Madariaga ~~coined the term~~ who introduced the "Mobility of Care~~, i.e., all the~~" framework to support the proper accounting of travel needed to fulfill ~~household needs~~ caring and home-related activities (e.g., ~~a combination of~~ the combined travel to grocery stores, errands, and ~~pick-up / drop-off of~~ picking-up or dropping off children) (Sánchez de Madariaga, 2013). ~~The term was developed to highlight how these~~ Mobility of Care highlights how household-serving ~~trips are~~ travel is systematically under-represented, under-counted, and rendered invisible ~~due to masculinist biases~~ in transport planning~~. Take, for instance, how trips to household sustaining destinations are categorized in typical large-scale travel surveys(Sánchez de Madariaga, 2013). In the Greater Golden Horseshoe Area' s (encompassing the Greater Toronto and Hamilton Area)~~, particularly in travel surveys. Travel surveys are a key source of mobility data for transportation planners in metropolitan cities, and their primary focus is on the collection of 'compulsory' trip purposes such as school and work. In the Canadian context, respondents of the Transportation Tomorrow Survey (TTS) ~~(Data Management Group, 2018a) respondents~~ which encompasses the cities of Toronto, Hamilton and surrounding urban area (Data Management Group, 2018a), are given the following options to categorize their trip origins and destinations: home, work, school, daycare, facilitate passenger, marketing/shopping, other, or unknown. While home-work and home-school trips are easily identified, care trips are more challenging to ~~measure. Many marketing/~~ discern. Likely, many shopping trips are ~~likely~~ for care purposes (e.g., groceries), but others ~~are likely~~ may be for leisure. While escort trips ~~are likely~~ may be well

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captured under the categories 'daycare' or 'facilitate passenger', trips to run errands or to attend health appointments ~~are not clearly captured. It~~ may not be; it is probable that ~~responds~~ respondents categorize many of these trips as 'other' or even 'unknown'. ~~The focus of the survey is on what is~~ Ultimately, the travel survey's focus is on a 'typical' trip to work or school (Data Management Group, 2018a); other trips are a by-product, ~~'non-typical' and~~ minimialised in importance. Of course, people's travel behaviours are complex and surveys must balance detail with summary. However, what is seen as a 'typical' trip continues to shape transport and land-use, and this aggregation steers data-driven solutions from counted and observed home -work/-school based trips.

When travel surveys ~~are~~ *are* designed to explicitly capture mobility of care, preliminary research has found that it comprises approximately one third of adults' trips ~~(Gómez-Varo et al., 2023; Sánchez de Madariaga, 2013; Sánchez d~~ (Gómez-Varo et al., 2023; Sánchez de Madariaga, 2013; Sánchez de Madariaga and Zucchini, 2019; Ravensbergen et al., 2 . Given the large proportion of daily travel that mobility of care comprises, these trips should be explicitly captured in transport research. Further, the current under-reporting of mobility of care in research and planning has important equity considerations. Not only are mobility of care trips completed predominantly by women, this gendered discrepancy is greater in low-income households (Murillo-Munar et al., 2023; Sánchez de Madariaga, 2013; Ravensbergen et al., 2022). For instance, in lower income households in the city of Montréal, women complete 50% more care trips than men (Ravensbergen et al., 2022).

The power of the Mobility of Care concept lies in its ability to highlight the masculinist bias in transport research – travel for care appears insignificant because travel surveys are not written to capture it (Sánchez de Madariaga, 2013).

Travel surveys, however, are but one ~~tool~~ source of information used by transport researchers and practitioners. Another popular ~~tool in transport planning and research~~ instrument is accessibility, ~~an indicator that quantifies "the potential of opportunities for interaction" as defined in the seminal work of Hansen (Hansen, 1959). Accessibility indicators can be interpreted as~~ especially in the case of sustainable and equitable cities (Ryan et al., 2023; Bertolini et al.). Accessibility is an indicator of the ease of ~~reaching destinations using transport networks: a byproduct of mobility and a representation of the people's interaction with land-use and transportation systems (Hansen, 1959; Handy, 2020; El-Geneidy and Levinson, 2021). The points~~ interacting with destinations. However, the point of interest in many accessibility-based assessments ~~have been home-to-work destinations (Kelobonye et al., 2019; Farber and Allen, 2019; Duarte et al., 2023; Ryan et al., 2023). For example, in~~

~~the accessibility assessment of the Ontario Line, a subway line that will be constructed in the city of Toronto, Canada, Farber and Allen (Farber and Allen, 2019) highlight how this new investment will increase access to jobs for residents across the City by 1.14% overall. While much has been learned, shifting focus from jobs as the default destination may open opportunities for gender-mainstreaming accessibility analyses. Indeed, jobs~~ has been travel to work destinations by car or public transit modes e.g., (Kelobonye et al., 2019; Farber and Allen, 2019; Duarte et al., 2023; Ryan et al., 2023). Jobs are not always the most significant destination for many segments of the population. ~~As discussed,~~ Further, modal options to employment and care trips differ. For example, women's commutes ~~comprise~~ are on average a smaller proportion of their daily travel than men's (Ravensbergen et al., 2022). ~~This focus on job-access can additionally bias accessibility-gains that children and older adults who reside in impacted areas may see as well (Grant-Smith et al., 2016)~~Care trips are also less likely to be completed by public transit or bicycle and are more likely done by car or by foot than the commute (Ravensbergen et al., 2022). One way to ~~counter this bias is to reframe accessibility analysis~~ apply a gender-aware lens to accessibility analysis is by explicitly considering access to destinations involved in ~~mobility of care.~~

~~Reframing accessibility analyses to incorporate mobility of care is also pertinent to the promotion of sustainable travel modes~~ Mobility of Care by multiple modes. Reframing accessibility analysis in this way reinforces its importance as an instrument that supports the planning of sustainable and equitable travel and land-use in cities. ~~Research has found that people are less likely to use public transport or bicycles for care trips (Ravensbergen et al., 2022) and more likely to make these trips by car (Maciejewska and Miralles-Guasch, 2019; Ravensbergen et al., 2022). A lack of access to care destinationsby bicycle and transit may contribute to these trends. Mobility of care is also more commonly completed by foot than the commute to work (Ravensbergen et al., 2022). Whether there is a relationship between these travel behaviors and people's access to care destination using different modes, however, remains unknown, as mobility of care is largely uncounted in transport research.~~

~~In this spirit, this study foregrounds the theoretical mobility of care concept by calculating the accessibility to care destinations or multiple modes in an empirical case study of Hamilton, Canada. Two place-based accessibility measures are used to motivate the discussion: one unconstrained measure (cumulative opportunity) and another competitive and constrained measure (spatial availability (Soukhov et al., 2023)). The cumulative opportunity measure demonstrates the potential access to all destinations within 15-minutes~~ Taken together, this study's objective is to contribute to the transport planning literature through the demonstration of a multimodal accessibility analysis of Mobility of Care destinations. Two accessibility measures are used: the cumulative opportunities measure and the spatial availability measure. The measures are applied on a care destination dataset with novel Mobility of Care classifications for the city of Hamilton, Canada. The potential access to Mobility of Care destinations for walking, transit, bike, and on foot is calculated for 15- and ~~30-minutes. This measure is~~ 30-minute travel time thresholds. Results are compared across the two measures and four modes, and the overlap between low accessibility areas and high low-income prevalence is presented. Implications of the results are discussed along with study conclusions.

2. Overview of multimodal accessibility analysis

As indicators of "the potential of opportunities for interaction" (Hansen, 1959), accessibility measures can also be interpreted as the relative ease of reaching destinations using transport networks: they are a byproduct of mobility and a representation of people's interaction with land-use and transportation systems (Hansen, 1959; Handy, 2020; El-Geneidy and Levinson, 2021).

The cumulative opportunities measure is a popular accessibility measure, widely appreciated for its intuitive computation (Handy, 2020; Handy and Niemeier, 1997; Kelobonye et al., 2019; Cheng et al., 2019)~~but critiqued for~~. It quantifies how many destinations can be reached from a point in space within a given travel time threshold. The measure has been used to quantify access, given a travel time threshold and mode, often to employment destinations. Namely, access to employment is explored by car and/or transit (Kapatsila et al.; Deboosere and El-Geneidy; Tomasiello et al., 2023), by bike (Imani et al., 2019), and by foot (Singh and Sarkar, 2022). Non-work amenities have also been analysed by this popular measure. For example, grocery stores (Hosford et al.) and 'baskets' of urban-amenities (McCahill, 2018; Klumpenhouwer and Huang, 2021; Cheng et al., 2019). From the authors' review, the cumulative opportunities literature has not yet focused on destination selection from the lens of Mobility of Care.

A critique leveled at the cumulative opportunities measure (and other non-competitive accessibility measures) is its omission of ~~competition~~ competition-for-opportunities effects (Paez et al., 2019; Soukhov et al., 2023; Kelobonye et al., 2020; Merlin and Hu, 2017). ~~To respond to this critic, spatial availability of care destinations per mode is also calculated as an additional and arguably more conceptually realistic reflection of opportunity availability. This research aims to contribute to gender-mainstreaming in~~

~~transport planning by demonstrating an approach to a feminist accessibility calculation through these two accessibility measures.~~ Conceptually, this consideration is important as opportunities are finite, which leads to competition between the population seeking them. However, planners often opt for simpler measures (Kapatsila et al.) as measures that account for competition tend to be more difficult to implement and interpret (Merlin and Hu, 2017). In the recent work of Soukhov et al. (2023), an accessibility measure named Spatial Availability is introduced that simplifies the interpretation of resulting values while considering competition using a proportional allocation. It is extended for multimodal applications in Soukhov et al.. Notably, the use of competitive accessibility measures to explore access to a variety of destinations is scarce, with only recent exceptions (e.g., Kelobonye et al. (2020) and Singh and Sarkar (2022)). Moreover, competitive accessibility measures have yet to be focused on Mobility of Care destinations.

As presented in this work, two multimodal accessibility measures are implemented for the calculation of accessibility to Mobility of Care destinations. The first is a routinely used measure, the cumulative opportunities measure, and the second is a competitive and singly-constrained measure, spatial availability (Soukhov et al., 2023; Soukhov et al.).

3. Background on Hamilton

This paper focuses on Hamilton as a case study, a mid-size city of approximately 500,000 residents that lies within the urban and suburban Greater Toronto and Hamilton Area ~~(GTHA) (Data Management Group, 2018a). The GTHA~~ and is home to seven million people, or approximately 20% of the Canadian population (Toronto, 2022).

Hamilton is divided into six regional communities (Figure 1). Hamilton-Central is the ~~densest and~~ most urbanized of the six, and the five periphery communities of Dundas, Ancaster, Flamborough, Glanbrook and Stoney Creek are significantly more suburbanized with the furthest periphery regions being undeveloped or rural owing to their inclusion in the region's greenbelt (Greenbelt Foundation, 2023). These different urban forms and associated transport infrastructure play a key role in access to care destinations.

~~Further, the entire manuscript and all analysis is conducted in R and RStudio. All work is computationally reproducible and openly available in the lead author's GitHub repository~~Hamilton Street Railway (HSR) is the city's transit provider operating only buses at the current date. Notably, Hamilton-Central is the only community fully serviced by HSR and has the highest concentration of walking and bike infrastructure for mainstream use (e.g., Level of Traffic Stress 1 or 2 which indicates low-speed, low-volume streets, separated bicycle facilities, and dedicated lanes where cyclist must interact with traffic at formal crossings (Conveyal)) as identified in the OpenStreetMaps road network (Geofabrik, 2023) and the city's General Transit Feed Specification file (Transit Feeds, 2023).

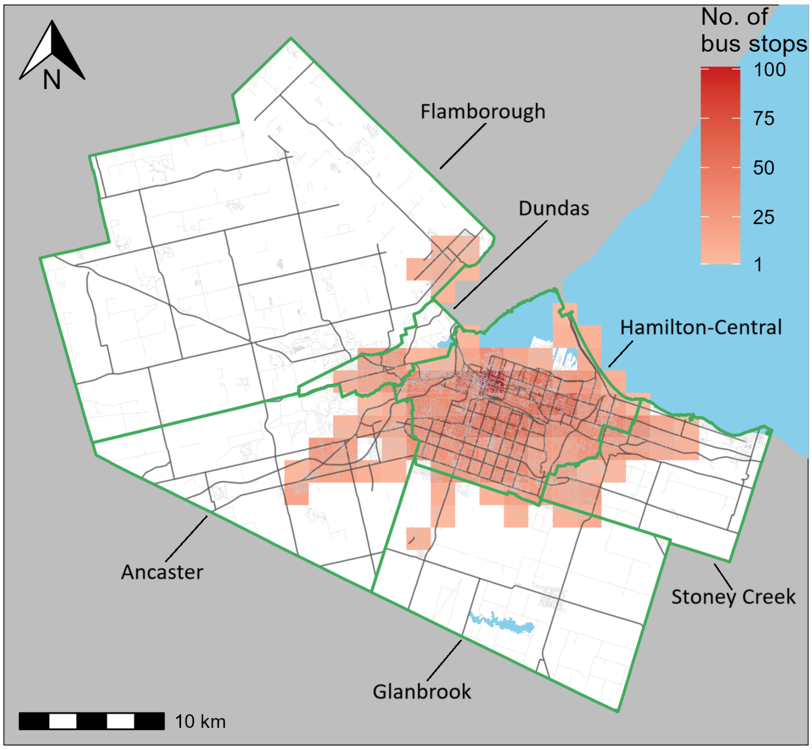

Figure 1: The six former muncipal boundaries in the city of Hamilton (green), highways and arerial roads (grey), walking and cycling infrastructure (light grey), and concentration of transit bus stops (reds). Geographic layer sources: road network (Geofabrik, 2023), transit stops (Transit Feeds, 2023), community boundaries (Hamilton, 2023a) and lake (USGS, 2010). ~~The six former muncipal boundaries in the city of Hamilton. Basemap shapefiles are retrieved from the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010). Highways and arterial roads are shown in light grey.~~

3.1. *Care destination dataset*

A novel geospatial dataset of care destinations for Hamilton ~~(e.g., full addresses of longitude and latitude) was compiled . The geospatial data was sourced from provincial and municipal open data portals (Ontario, 2023; Hamilton, 2023b), Data Axle, a consumer dataset compiled of businesses and companies within Canada (Axle Data, 2023) or manually~~ was compiled using a variety of local sources and manually confirmed through Google Maps. ~~Each destination was categorized based on the specific type of care being accessed following the~~ As a way to showcase the dataset, it is grouped by care destination category. These five categories were generated by the authors following the travel purpose categories created in the mobility of care research by ~~Sanchez de Madariaga & Zucchini (2019)(Sánchez de Madariaga and Zucchini, 2019).~~ ~~Categories include child, elder, grocery~~ Sánchez de Madariaga and Zucchini (2019). Notably: child-centric (destinations for "Childcare" escorting trips), ~~health, and errand -centric destinations~~ elder-centric (common destinations for other escorting trips that are not childcare-focused), grocery-centric, health-centric, and errand-centric destinations. The majority of destinations included can be publicly accessed (e.g., only public schools, grocery stores, clinics, community centres). However, certain destinations may require a fee that could be prohibitive for lower-income households (e.g., all long term care homes, both publicly subsided or private are included). Category sources of data and preparation notes are detailed in Table 1. Their spatial distribution and sub-categories are visualised in Figure 2.

Table 1: Details on the preparation and data sources of care destinations.

Care category	Sources	Data preparation notes
Child-centric	(Hamilton 2022a, 2023, 2022c, 2022d; Ontario 2023b)	Public schools, public and private (licensed) daycares, and public community centres, public recreation centres, and public parks: 1,190 locations are included. After manual review, all locations that typically do not serve children were removed including: Post-Secondary, Adult-Learning Centres, Group Homes, and Foster Care Centres. Further, through examination some Section 23 institutions defined as *"centres for children who cannot attend school to meet the needs of care or treatment, and rehabilitation"* (Ontario 2023a), were kept due to their innate connection to care.
Elder-centric	(Hamilton 2022d; Ontario GeoHub 2023)	Senior centres, long-term care homes, and retirement homes: 75 destinations are identified.

Care category	Sources	Data preparation notes
Grocery-centric	(Axle Data 2023)	Grocery stores, namely a place a household could buy groceries ranging from convenience stores to large retail stores: 381 destinations are identified. Data is filtered by Company Name, Suite Number, Address, City, Province, Phone Number and Postal Code. The type was then identified e.g., grocers specialty foods, grocers retail, grocer health food, grocer wholesale, grocer curbside, grocer delicatessen wholesale, grocer convenience. Data was crossreferenced to ensure all included locations were operational and legitimate grocery stores.
Health-centric	(Ontario GeoHub 2023; HNHB Healthline 2023)	Hospitals, pharmacies, clinics, and dentist offices: 421 destinations are identified. Hospitals and pharmacies were retrieved while clinics and dentistry clincs were manually scraped from a healthcare services database and checked via Google Maps to remove non-operational locations and confirm dentistry-orientation.

Care category	Sources	Data preparation notes
Errand-centric	Hamilton libraries (Hamilton 2022b), post office locations (Axle Data 2023; Canada Post 2023), and datasets of all national bank chains (BMO 2023; HSBC 2023; National Bank 2023; RBC 2023; Scotiabank 2023; TD Bank 2023).	Libraries, post offices, and banks: 158 destinations are identified. Post offices are retrieved from a mix of databases, and duplicates are removed. Banks are also derived from Data Axle and then cross-referenced to ensure data quality with a Bank Locator website for all national banking firms.

~~For the purpose of this analysis and in absence of city-wide household preferences for care destinations, all locations are re-weighted to make each of the six categories conceptually equivalent i.e., each location within each category c is weighted to equal $O_c = \frac{1}{\sum_{c=1}^{6} c} \frac{\sum_{c=1}^{6} J_c}{J_c}$ where J_c is the number of locations within a category c. If this was not done, the results would favour access to child-centric destinations as they make up the majority of the dataset. Accessibility literature has weighted destinations (amenities) using a variety of method such as estimated capacity of destinations (Li and Wang, 2024) or origin-destination flows from travel surveys (Graells-Garrido et al., 2021; Cheng et al., 2019). This work's focus is on household-serving care destinations, so many destinations do not have traditional 'capacities' like health care facilities have beds. Origin-destination flows to all care destinations also have not been counted within the TTS~~

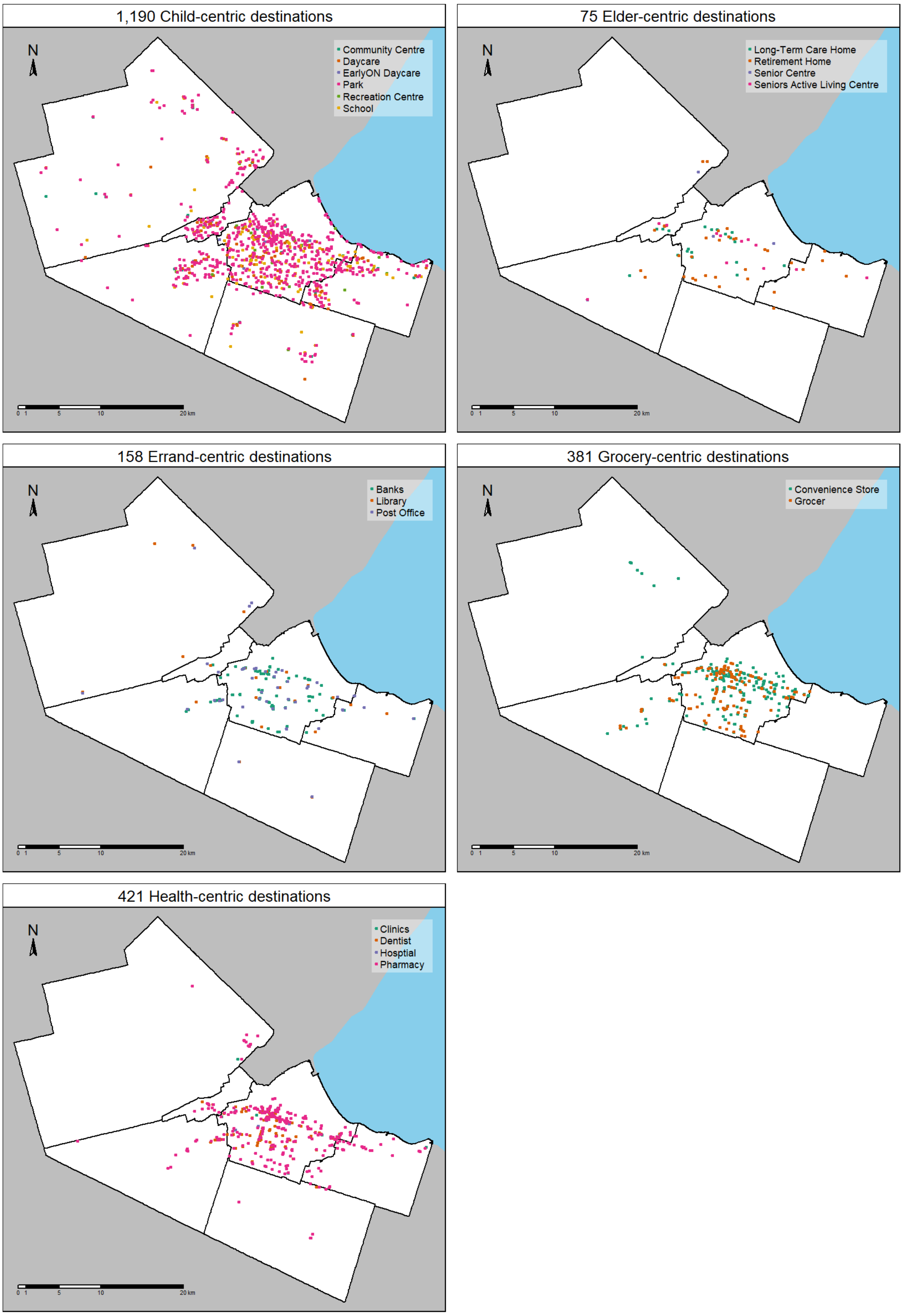

Figure 2: The geo-located points of care destinations in the City of Hamilton separated by the author-generated categories of: child-, elder-, errand-, grocery- and health- centric care categories. Locations of these destinations were retrieved through multiple sources as described in the text. Basemap shapefiles are sourced from the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).

~~(Data Management Group, 2018a). So, in this analysis, the five care categories are re-weighted to represent one-fifth of the dataset. Conceptually, this simplistic re-weight assumes the population potentially interacts with all categories and all locations within each category equally. In absence of empirical data for amenity weight calibration, this methodological assumption is a limitation.~~

3.2. Population data

- ~~Child-centric (1190 destinations each at 0.3739496),~~
- ~~Elder-centric (75 destinations each at 5.9333333),~~
- ~~Errand-centric (158 destinations each at 2.8164557),~~
- ~~Grocery-centric (381 destinations each at 1.167979) and,~~
- ~~Health- centric (421 destinations each at 1.0570071) .~~

To supplement the care destination dataset and complete the accessibility calculation (discussed in the followng section), population data for the City of Hamilton is sourced from the 2021 Canadian census using the {cancensus} R Package (Statistics Canada, 2023a; von Bergmann et al., 2021). Three categories of variables are selected: the population, the percent of after-tax low-income-cut-off (~~LICO-AT~~LICO), and the primary commute mode used. ~~LICO-AT~~ LICO is a composite indicator included in the census that reflects the proportion of households spending 20% more than the area average on food, shelter and clothing (Statistics Canada, 2023b). As stated in the Introduction, women, especially those in low-income households, preform the majority of care trips. However, since the proportion of women and men residing across the city is balanced, this study focuses on the total population and total LICO prevalence. All data was sourced at the most granual level of spatial resolution publicly available, the level of the dissemination area (DA).

Figure 3 displays the spatial distribution of the total population and ~~the prevalence of LICO-AT~~ LICO prevalence as a percentage of the total population. ~~Of note is~~ Notably, the density of population within Hamilton-Central (oranges) and the cluster of high density and high ~~LICO-AT~~ LICO prevalence near the shoreline in Hamilton-Central (dark purple-oranges).

Further, the population proportion that commutes by a specific mode (car, transit, walk, or cycle/other) is visualised in Figure 4. Though mode-choice used in travel to work is not necessarily reflective of the mode used to travel to care destinations, ~~to our knowledge~~ no other data is available at a granular level City-wide that centers mobility of care to our knowledge. The population generally commutes by car (50% or higher,

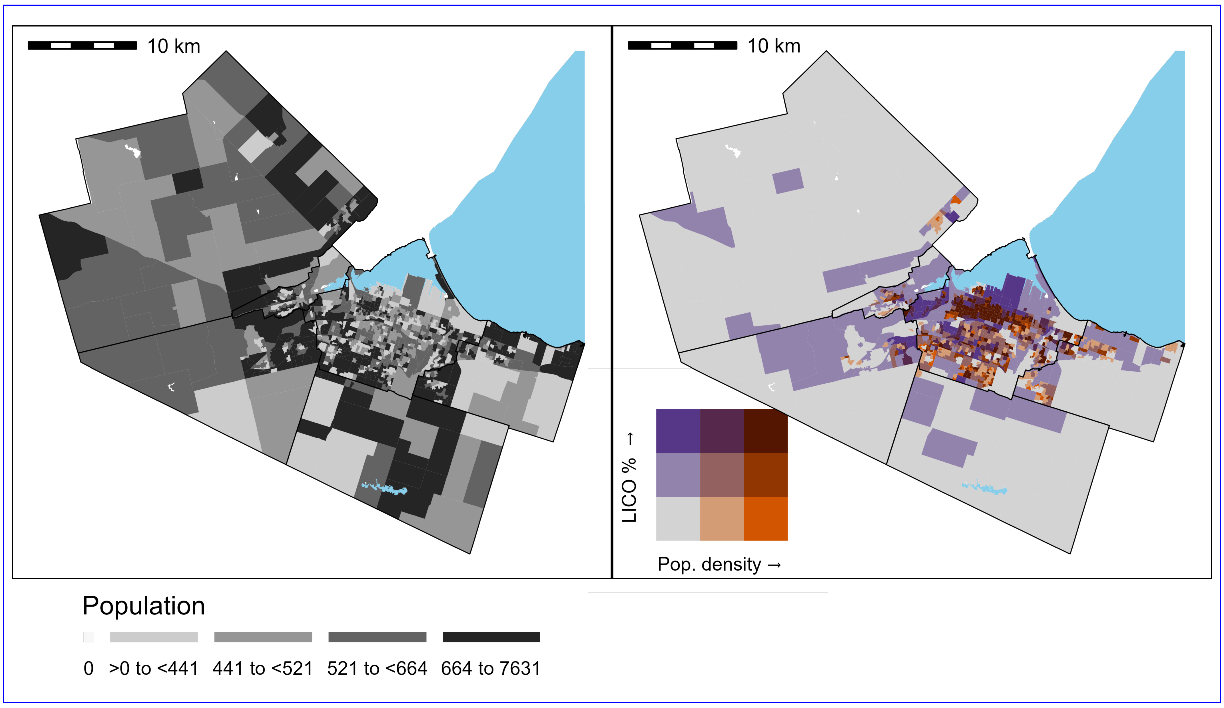

Figure 3: The total population in each dissemination area (DA) as provided in the 2021 Canadian census (Statistics Canada, 2023a), visualized within the six community boundaries in the city of Hamilton. The left plot represents the population and the right represents the population density versus the low-income cutt-off after taxes (LICO) as a percentage of the total DA population. LICO is a measure of economic disadvantage. The legend categories represent quartiles. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).

~~The total population in each dissemination area (DA), visualized with the six former muncipal boundaries in the city of Hamilton. The left plot represents the population and the right represents the population density versus the low-income cutt-off after taxes (LICO-AT) as a percentage of the total DA population. LICO-AT is a measure of economic disadvantage. The legend categories represent quartiles. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).~~

is yellow to green), even within the more densely populated Hamilton-Central. However, for transit and walking, a group of DAs near the shoreline within Hamilton-Central have the highest proportion of transit users and those who walk to work (yellows in the plots that are otherwise red i.e., below 15%). Those same DAs are also relatively dense and have a high prevalence of ~~LICO-AT~~ LICO (Figure 3).

3.3. Transportation network and travel time estimations

As empirical travel behaviour to care-oriented destinations is uncounted ~~, it is approximated in the estimation of travel time to all locations~~and thus travel time is unavailable, travel time is approximated. Travel times by walking, cycling, transit and car is calculated for ~~each DA to the destination point~~ the geometric centroids of the DAs to the geometric centroids of the care destination location using the 'travel_time_matrix()' function from the {r5r} package (Pereira et al., 2021). Inputs are point locations of ~~origins~~DA centroids (origins), care destinations centroids, ~~destinations,~~ an OpenStreetMap road network including bike, transit and vehicle infrastructure (Geofabrik, 2023), and city GTFS transit routes/schedules (Transit Feeds, 2023). ~~The origin of each DA and destination location is assumed to be its geometric centroid.~~ For all modes, travel times under 60 minutes based on the shortest travel-time path are calculated.

For transit and cycling, additional parameters were included. For transit travel times, a Wednesday departure time of 8:00AM was selected (Boisjoly and El-Geneidy, 2016) with a departure travel window parameter of ~~±~~ 30 mins. Travel times are calculated for each minute of the travel window (~~7:30-8~~8:00-8:30AM) and the 25th percentile from the distribution of travel window times were selected to represent each origin-destination. Selecting a sufficiently wide window is an important consideration as travel times are sensitive to transit vehicle frequency and connecting transfers (see discussion of the modifiable temporal unit problem e.g., (Pereira, 2019)). The 25th percentile indicates that 25% of trips from that origin to destination have a travel time that is that length or shorter. This assumption provides an optimistic perspective of transit travel times. For cycling travel times, level 1 or 2 traffic level of stress routes (i.e., dedicated or separated cycling lanes respectively) were selected. The level of traffic stress is a variable associated with links of the OSM road network; level 1 and 2 are considered the default.

~~The **cumulative opportunity** and **spatial availability** measures are used to estimate the potential access to care that each mode provides to the DA. From the cumulative opportunity measure , the DA level values represent the potential interaction with reachable destinations~~

4. Accessibility measurement methods

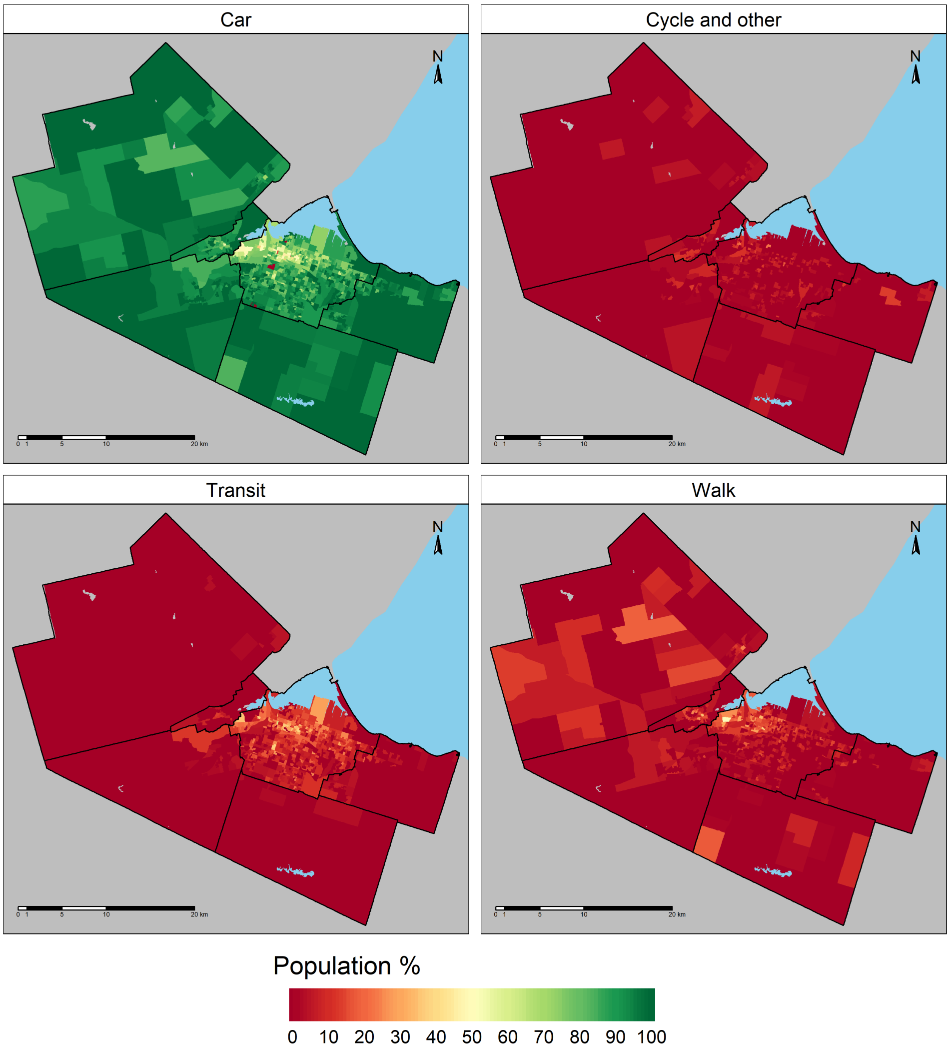

Figure 4: The proportion of mode type used for commuting (aged 15 and older employed in the labour force) in each dissemination area (DA) as provided by the 2021 Canadian census (Statistics Canada, 2023a). Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).

~~The proportion of mode type used for commuting (aged 15 and older employed in the labour force) in each dissemination area (DA) as provided by the 2021 Canadian census. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).~~

Two accessibility measures are detailed: the cumulative opportunities measure and the spatial availability measure. Both yield a value per spatial unit that represents how many care destinations can be reached within a given travel time, for a ~~population located at DA could access using a~~ given mode. ~~The interpretation of the spatial availability measureis different: each DA level values are a proportional value of all the care destinations in Hamilton. Each proportional value represents the potential availability of reachable care destinations to a mode-using population located at the DA.~~ However, both measures have different underlying assumptions; the first does not consider competition effects and the second does.

~~**Cumulative opportunity accessibility**:~~

4.1. Cumulative opportunities: the number of care opportunities that can be reached by a mode within a travel time

Often referred to as the cumulative opportunities measure, it is a special form of the gravity-based accessibility measure used in at least as far back as Hansen (1959; Handy and Niemeier, 1997). Its name is drawn from its' interpretation: the value calculated for each spatial unit (DAs in this study) represents the number of opportunities that can be spatially accessed within a given travel time. The cumulative opportunities accessibility measure takes the following general form for ~~multi-modal~~ a multimodal calculation:

$$S_i^m = \sum_j O_j \cdot f^m(c_{ij}^m)$$

Where:

- i is a set of origin locations ~~.~~ (e.g., DA centroids)
- j is a set of destination locations ~~.~~ (e.g., care destinations)
- m is a set of modes ~~.~~ (e.g., by foot, cycle, transit and car)
- O_j is ~~a~~ the number of opportunities at j ~~, in our case weighted.~~ (e.g., the presence of a care destination in this study)
- c_{ij}^m is the travel cost between i and j for each m.
- $f^m(\cdot)$ is an impedance function of c_{ij}^m for each m; within the cumulative ~~opportunity approach~~opportunities measure, it is a binary function that takes the value of 1 if c_{ij}^m is less than a selected value~~(Handy and Niemeier, 1997)~~.
- S_i^m is the ~~unconstrained accessibility for~~ cumulative opportunities accessible by m at each i.

~~**Spatial availability**, on the other hand~~

4.2. *Spatial availability: the number of care opportunities that are spatially available to a mode-user within a travel time*

Differing from cumulative opportunities measure, the spatial availability measure considers competition leading to a different interpretation in its results. The values for each origin i (in our study, DAs) for a given mode m represents the number of care opportunities that can be accessed by a mode-user out of *all* care opportunities in Hamilton. Spatial availability considers competition through proportional allocation of opportunities to a given i based on the relative proportion of population computing for an opportunity and their travel times. Each V_i value represents the potential availability of reachable destinations. Spatial availability, takes the following general form for ~~multi-modal~~ multimodal calculation:

$$V_i^m = \sum_j O_j \; F_{ij}^{tm}$$

Where:

- Like in Equation (1), i, j, and m is a set of origin locations, destination locations, ~~and modes respectively .~~
- modes respectively and O_j is ~~a~~ the number of opportunities at j~~, in our case weighted~~.
- V_i^m is the cumulative opportunities spatially available by m-using population at i for each i.
- F_{ij}^{tm} is a total balancing factor for each m at each i~~. It depends on~~ ; it considers the size of the populations at different locations that demand opportunities O_j, as well as the cost of movement in the system $f(c_{ij})$.
- ~~V_i^m is the constrained accessibility (spatial availability) for m at each i; the sum of V_i^m for all m at each i is equivalent to the total sum of opportunities in the region (i.e., $\sum_j O_j = \sum_i V_i = \sum_m \sum_i V_i^m$).~~

What makes spatial availability stand apart from other competitive measures is the multimodal balancing factor F_{ij}^{tm} ~~(see ?Soukhov et al., 2023)~~(Soukhov et al., 2023). F_{ij}^{tm} implements a proportional allocation mechanism that ensures the sum of all spatial availability values ~~at each i~~ V_i^m across all modes m in the region always matches the total number of opportunities ~~in the region.~~ (i.e., $\sum_j O_j = \sum_i V_i = \sum_m \sum_i V_i^m$). This constraint helps in clarifying the interpretation of the V_i^m value itself.

The total proportional allocation factor F_{ij}^{tm} consists of two parts: the first is a population-based proportional allocation factor F_i^{pm} that models the mass effect (relative population-demand for opportunities) and the second is an impedance-based proportional allocation factor F_{ij}^{cm} that models the cost effect (relative travel time). Both factors consider competition through proportional allocation: F_i^{pm} estimates a proportion of how many people are in each i and using each m relative to the region and F_{ij}^{cm} estimates a proportion of the cost of travel from i to j at each i using each m relative to the region. Since F_i^{pm} and F_i^{mc} are proportions, $\sum_m \sum_i F_i^{pm} = 1$ and $\sum_m \sum_i F_i^{cm} = 1$. Both factors are combined to create the total balancing factor F_{ij}^{tm} used to calculate V_i^m:

$$F_{ij}^{tm} = \frac{F_i^{pm} \cdot F_{ij}^{cm}}{\sum_m \sum_i F_i^{pm} \cdot F_{ij}^{cm}}$$

Where:

- The factor for allocation by population for each m at each i is $F_i^{pm} = \frac{P_i^m}{\sum_m \sum_i P_i^m}$. This factor makes opportunities available based on demand.
- The factor for allocation by cost of travel for each m at i is $F_{ij}^{cm} = \frac{f^m(c_{ij}^m)}{\sum_m \sum_i f^m(c_{ij}^m)}$. This factor makes opportunities available preferentially to those who can reach them at a lower cost.

~~The travel impedance threshold used in both measures is~~

4.3. Travel impedance function selection

A binary travel impedance function $f^m(c_{ij}^m)$ is assumed (e.g., c_{ij} is equal or below a certain travel time threshold, $f^m(c_{ij}^m)$ equals 1, otherwise, $f^m(c_{ij}^m)$ equals 0). Two travel time thresholds are selected for both measures: 15 ~~minutes and 30 minutes; each measure is calculated eight times, once for each four modes and assuming a travel time cut-off of 15~~ minutes ~~or less and another assuming a travel time cut-off of~~ and 30 minutes ~~or less. The selection of travel time thresholds~~ for all modes.

This selection is informed by a scan of the literature. ~~Only one study to date has calculated the average travel time to all different categories of care destinations (16 minutes by car and 36 by public transport) (Ravensbergen et al., 2022). Other literature typically considers trips~~ Typically, literature considers travel to one type of care category (e.g., health, or school, or grocery stores) ~~Here, travel times vary by care category~~ and each destination type is associated with different travel impedance behaviour (e.g., grocery shopping trips are on average 15 ~~minutes to grocery shopping (Hamrick and Hopkins, 2012) or 20.45 for cancer treatments (Segel and Lengerich, 2020)~~minutes (Hamrick and Hopkins, 2012), trips to receive cancer treatments are on average 20 minutes (Segel and Lengerich, 2020)). In other care-related accessibility analyses, ~~time-cut offs~~ travel time thresholds of include 10 mins (for daycares) (Fransen et al., 2015) and 30 mins to 1 hr (for hospitals) (Schuurman et al., 2006) ~~. 15 and 30 minutes were selected to~~ are selected. Of the one study to-date that has calculated the average travel times to all different categories of care destinations, travel times to each care category differ by mode e.g., 16 minutes by car and 36 minutes by public transport (Ravensbergen et al., 2022). To broadly reflect this past research~~. The~~: 15 and 30 minutes are selected for all modes.

Notably, the use of a binary travel ~~time threshold,~~ impedance functions as opposed to ~~more complex impedance functions, was~~ a distance-decay impedance function, were selected to simplify communication of the assumed travel behaviour. As mentioned, lacking region-specific empirical data regarding care-centric travel, this work establishes a methodology to streamline access to care interpretation and analysis for when that data is available.

~~This work uses both constrained and unconstrained accessibility measures to elucidate different interpretations of access to care. As an unconstrained measure, cumulative opportunity measure counts all the destinations~~

5. Results

5.1. Spatial access to care opportunities

The cumulative opportunities and spatial availability plots for each mode, for both 15-minute and 30-minute travel time thresholds are shown in Figure 5. Each cumulative opportunities value represents a cumulative count of care opportunities that can be ~~reached~~ spatially accessed by each mode from each DA~~within a travel cost, for each DA. From a region-wide perspective, a destinationthat can be reached is counted multiple times by all DAs that can reach it, so the sum of all cumulative opportunity DA values in the region is not meaningful. Simply, if walking-mode provides access to some number of opportunities within a 30 minutes, car-mode provides some greater access within 30 minutes, and the access that walk-mode is not discounted by the population using car-mode and the greater number of opportunities they can potentially access. However, cumulative opportunity measure is intuitive to implement, a part in why it has been widely adopted in accessibility research and considered a introductory method to more advanced accessibility measure (El-Geneidy and Levinson, 2021).~~

~~On the other hand, spatial availability is constrained accessibility measure that considers competition~~

~~(Soukhov et al., 2023). It incorporates the concept of the *finite*: opportunities are numbered in the region so they can be potentially interacted with more or less based on the travel impedance offered by the zone (~~, where each opportunity represents a reachable care destination. In this case study, the spatial availability measure presents a constrained interpretation of this measure; each value is a cumulative count of care opportunities that can be spatially accessed from each DA *and are spatially available to the mode-using population based on the relative size of the mode-using population and modal travel times.* As proportional allocation is used, each spatial availability value can also be interpreted as the *spatially available* proportion of the total care destinations in the city, i.e., the ~~travel cost on the transport network) as well as how densely or sparsely the zone is populated with opportunity-seeking opportunities. This is especially important considering population-distinct characteristics like selected travel modes. In a North American context, car-modes can potentially access more opportunities (unconstrained) because of their higher range relative to transit. But if opportunities are considered finite, high car mobility may take-up a higher share of opportunities from populations using modes that offer lower mobility, especially in zones where there is a high population and car-using modal split. Cumulative opportunities does not consider the relative population-demand for care destinations while spatial availability does: the use of these two measure illustrates distinct results.~~

~~The cumulative opportunity accessibility plots for each mode are shown in~~ sum of all spatial availability values in the second row of Figure 5 ~~. They visualise an unconstrained count~~ equal 2,225, the total number of care destinations ~~that can be reached by each mode from each DA. The higher the zonal~~ in this case study.

In both measures, the higher the value, the more potential interaction with care ~~destinations~~opportunities. This greater potential of opportunity of interaction is conceptualised as a positive outcomes of well functioning land-use and transport networks (Cordera et al., 2019; Blumenberg and Pierce, 2017; Cui et al., 2020). ~~Spatial~~ In Figure 5, values are grouped by quantile and spatial trends between the 15-min and 30-min threshold plots are ~~similar (values are grouped by quantile). Three significant~~ highly correlated (0.92 for cumulative opportunities and for 0.89spatial availability).

When considering the cumulative opportunities measure; three notable findings between modes can be identified. First, ~~the access that the car-mode provides is significantly higher relative to other modes. Travel by car results in the greatest maximum number of potential interactions to care destinations (1939 opportunities for 15-min and 2209 opportunities for 30-mins). Next~~access by transit and walking is somewhat

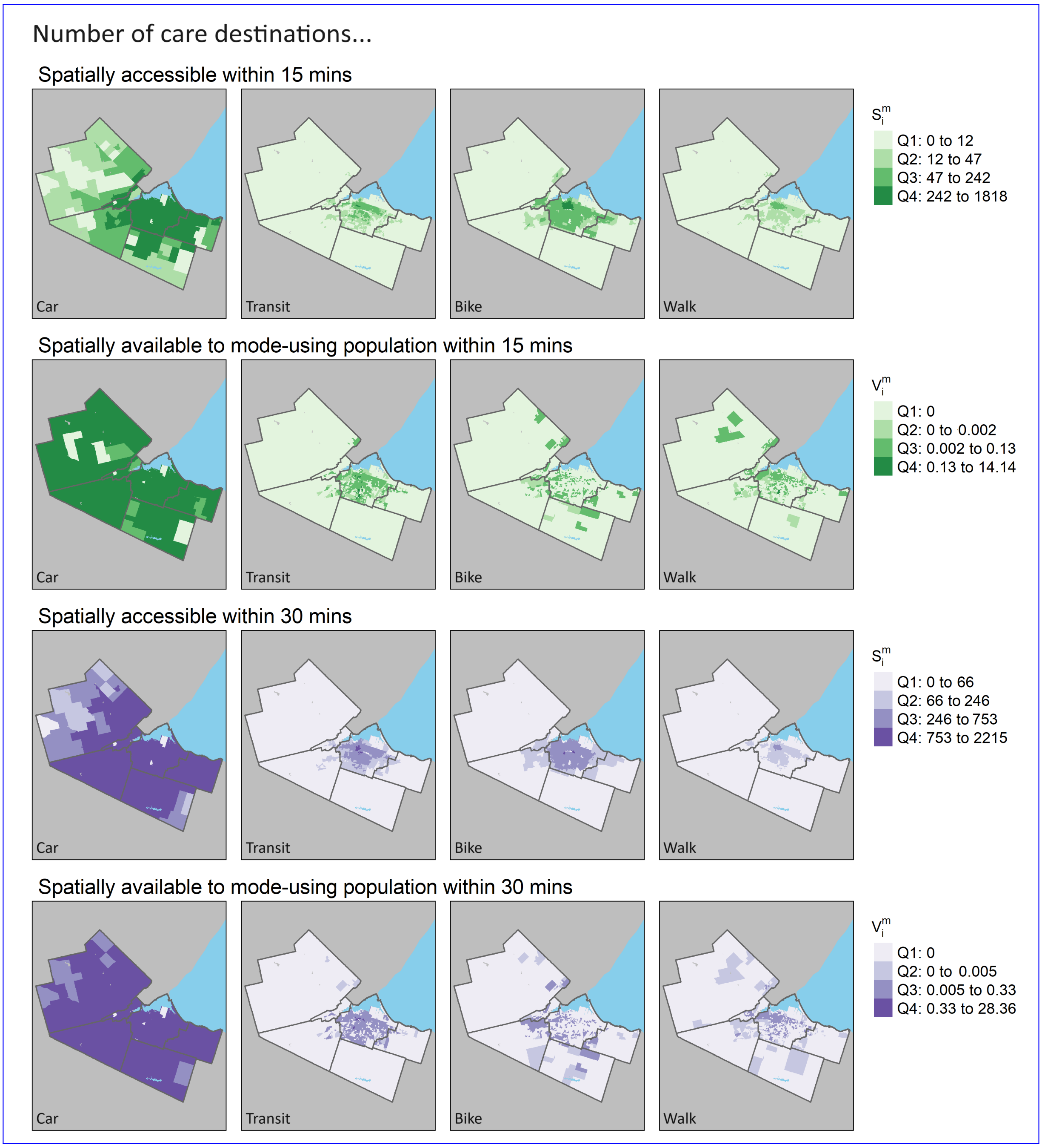

Figure 5: The number of care destinations that can be reached, per DA, within 15 mins (top) and 30 mins (bottom) for the cumulative opportunities and spatial availability measures. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).

high (mostly Q3 and some Q4) within the core of Hamilton-Central but low elsewhere. This finding is somewhat expected as as transit does not significantly serve communities outside of Hamilton-Central and Dundas and the density of walking infrastructure is high in Hamilton-Central (see Figure 1). Second, access by cycling is ~~also relatively high. It~~ even higher (mostly Q3 but more Q4) in Hamilton-Central; it provides the second most opportunities for interactions after travel by car, and affords at least one opportunity for interaction in more DAs than walking and transit use ~~. Finally, access by transit is high and walking is also relatively high within Hamilton-Central but low elsewhere.~~

~~The cumulative opportunity measure. The number of care destinations that can be reached, per DA, within 15 mins (top) and 30 mins (bottom). Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010)~~ ~~.~~

~~From Figure 5,~~ (notably some access (Q1) in rural communities). Third, the access that the car-mode provides is significantly higher relative to the three sustainable modes. Travel by car results in the greatest maximum number of potential interactions to care destinations (1818 and 2215 opportunities within 15-min and 30-mins respectively). Car-mode offering high accessibility to care destinations is an expected outcome given the car-oriented design of North American cities (Saeidizand et al., 2022) ~~. However, access by non-car modes is great within many DAs in Hamilton-Central (Q3 and Q4). As well, cycling provides some access to destinations (Q1) in more rural communities. While~~ and the range (travel speeds over a distance) of the car mode. However, though car ownership is high in Hamilton, not everyone has access to a private vehicle~~:~~. For instance, 13% of Hamilton households own zero vehicles (Data Management Group, 2018b)~~.~~ ~~Unconstrained~~ , presenting equity concerns in who may benefit from the high accessibility car-mode offers. The cumulative opportunities access is insightful in illustrating the ~~spatial accessibility to destinations that people may have, but it~~ range in which opportunities can be accessed by each mode based on their travel speed (on available infrastructure); a summary of each origins' modal opportunity isochrone. However, the cumulative opportunities measure does not account for ~~how the overall access provided by the transportation systems to destinations is allocated to different~~ competition effects. Namely, what proportion of the modal opportunity range is *spatially available* to a mode-user at a given location when competing for those same opportunities with other mode-users. Considering competition in this way conjures richer conclusions that reflects the mode-using ~~populations. This lack of consideration may conjure misleading conclusions , namely the inflated promise of lower access-providing modes.~~

~~Consider cycling: the access provided by this mode appears promising when examining the cumulative opportunity results (~~population. For instance, consider cycling, a mode that offers a relatively high range but still smaller than the car. The cumulative opportunities values in Figure 5 ~~). This may be in part because interpreting cycling access against the much higher access providing car-mode is difficult. Unconstrained access by car is high (Q4), but at least cycling-mode can achieve~~ reflects this intuition: Q3 ~~levels~~ and Q4 cumulative opportunities values are present for cycling in Hamilton-Central~~and Q1 beyond. However, by conceptualising the amount of accessibility available in the region as a total, one can answer how many opportunities are available to those using the cycling-mode considering the allocation to the other three~~, offering the second best cumulative opportunities after the car. However, bike spatial availability values depicts a more complex story of opportunity accessibility: it reflect the mode's opportunity range as well as proportion of mode-using ~~populations. This comparison cannot be addressed using unconstrained accessibility, but can be explored with spatial availability (constrained accessibility), mapped in Figure 6.~~

~~Spatial availability: the number of care destinations that can be reached, per DA, within 15 mins (top) and 30 mins (bottom). Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010) .~~

~~This study's calculation of spatial availability (Figure 6) assumes population mode-shares (proportions shown in Figure 4), while the unconstrained analysis does not. In this context, from Figure 6 it can be observed that those who use car-modes are allocated the most spatial availability i.e., the proportion of spatial access to destinations out of all spatial access to destinations in the region. A similar spatial trend is found in the unconstrained accessibility analysis (Figure 5). However, since Figure 6 accounts for the mode-using population~~population and how their range relatively compares to all other modes. The bike-using population is small (2% of the population), with many DAs having no or low proportions of bike-users. Meaning DAs with no bike-users are proportionally allocated no access to opportunities (zero spatial availability) and DAs with a small proportion of cyclists have relatively slow travel speeds compared to the car-using population. Though bike mode offers a relatively high opportunity range (cumulative opportunities), ~~the results are more rich. Spatial availability for motorists is in-part due to the exceptionally high proportion of car-using populations (especially in rural communities) as well as car-mode's relatively competitive travel time. There is a higher car-using population and the car-mode has low travel times to destinations allowing the car-mode using populationin each DA to capture the majority of spatial availability.~~

~~Figure 5 only sheds light on how much unconstrained accessibility the car-mode could potentially provided to people within a DA.~~ because of the low proportion of cyclist and their opportunity range compared to the *many* other mode-users, they receive low spatial availability values.

~~While the unconstrained accessibility analysis (Figure 5)demonstrates that non-car modes are promising in urban areas, as well as cycling in rural communities, Figure 6 demonstrates a more nuanced perspective. Though non-car modes may provide good unconstrained accessibility within Hamilton-Central (and some access in rural communities), they do not provide similar levels of spatial availability . Car-using populations capture more spatial availability, even in the centre of Hamilton-Central, than all other modes. Note the lower number of Q3 and Q4 values within and radiating outwards from Hamilton-Central for non-car modes in Figure 6 compared to Figure 5. Differences between the two measures follow a similar descriptive trend for both travel times.~~

~~The proportion of spatial availability allocated to a mode-using population can also be directly compared. This sheds~~ In the case study, spatial availability values reflect the proportion of cumulative opportunities accessibility to the mode user (based on relative population and travel times), which can be used to shed light on what mode, and in what region, a mode-using population captures more than its equal share of spatial availability. Overall, ~~97~~98% of the spatial availability is taken by motorists (destinations within 30-minutes) but they only represent 87% of the population~~;~~. Therefore, they have disproportionately more availability than their population's presence in the city. ~~They~~ Motorists capture this availability from ~~non-car mode using populations that exists in high proportions~~ populations that do not use cars, and as a result are left with lower spatial availability~~(i.e.~~. For instance, transit users that have access to destinations within 30-minutes ~~are~~ represent 7% of the population but ~~take~~ claim only 2% of the spatial availability~~, 30-minute cyclist are~~. Similarly, though cyclists and pedestrians represent 2% ~~of the population but represent 0.3% of the spatial availability, and 30-minute walkers are~~ and 4%of the population ~~but are allocated~~ respectively, they only capture 0.3% (cyclist) and 0.3% (pedestrian) of the spatial availability.

~~The key interpretation from Figure 6 is that if certain modes capture an exceptional proportion of availability, than the availability left for other modes is lower overall. This~~ In other words, if certain mode-users capture a greater proportion of spatial availability, then there is less spatial availability remaining for other mode users. Spatial availability does not necessarily have to align with the ~~unconstrained accessibility that mode offers~~cumulative opportunities that the mode offers, it is simply a constrained version that considers competition by mode-using populations. As noted, non-car modes have the potential to offer higher ~~unconstrained access~~ cumulative opportunities (within Hamilton-Central)~~in Figure 5. But~~ , but as it exists ~~(~~assuming modal commute shares~~)~~, the majority of spatial availability to care destinations can still be captured by motorists even in DAs where car mode share is under 50% (such as Hamilton-Central, see proportions in Figure 4).

Taken together, though non-car modes may provide somewhat good access to care destinations within Hamilton-Central (and some only some access in rural communities), they do not provide similar levels of spatial availability. Car-using populations capture more spatial availability, even in the centre of Hamilton-Central, than all other modes. Note the lower number of Q3 and Q4 values within and radiating outwards from Hamilton-Central for non-car modes for cumulative opportunities measure compared to spatial availability. This indicates that cumulative opportunities measures may overestimate the access to care destinations that non-car modes (pedestrians, cyclists, and transit users) have available to them.

5.2. Spatial availability and low-income mismatch

To draw insights on who may reside in DAs where populations are ~~advantaged with higher~~ disadvantaged with low modal spatial availability and high low-income prevalence, a cross-tabulation ~~of low-high spatial availability & LICO-AT prevalence and high-no spatial availability & LICO-AT prevalence~~ is visualised in Figure ~~??~~6. The modal spatial availability is divided by the mode-using population in each DA, resulting in the rate of modal spatial availability. LICO prevalence is the proportion of population that falls below the ~~LICO-AT~~ low-income cuttoff threshold (see Figure 3). Figure ~~??~~ 6 can be interpreted as follows: residents who use a specific mode in a "yellow" DA reside in a DA that offers below average spatial availability (i.e., below or equal to the the 50th percentile (median) levels of spatial availability per mode-using population) and the population within the DA has a high LICO-prevalence (i.e, 80th percentile or higher (8.4% or more)).

Notice the green DAs for the car-driving population and presence of yellow DAs for non-car modes within Hamilton-Central: Figure ~~??~~ 6 reinforces findings from Figure ~~6~~5. Even in Hamilton-Central where there is high proportion of ~~LICO-AT~~ LICO prevalence, car-mode using populations who reside in green DAs are still offered high levels of spatial availability. However, car ownership is not always possible for low-income households and the lack of ownership acts as a barrier to accessing economic and economic-support opportunities for low-income households (Morris et al., 2020) when alternative modes are insufficient (Klein et al., 2023). For this reason, populations below the ~~LICO-AT~~ LICO may rely on non-car modes, and the introduction of policies that increase access to care-destinations could be considered. The majority of yellow

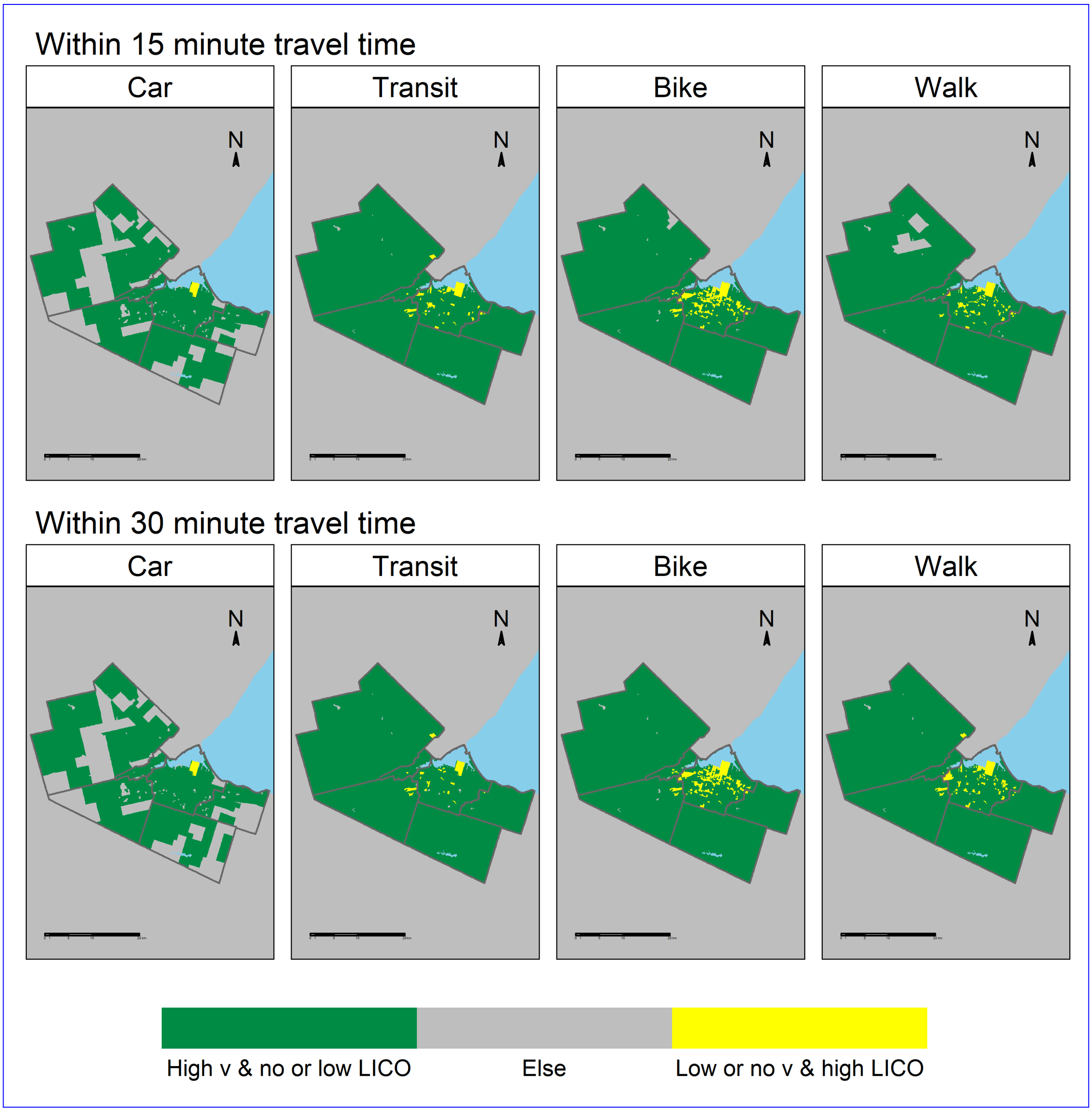

Figure 6: The spatial availability per mode-using-capita measure versus LICO prevelance, visualized for 15 mins (top) and 30 mins (bottom) travel time cutoffs. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a) , the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).

~~The spatial availability per mode-using-capita measure versus high-income cut-off . The number of care destinations that can be reached per mode-using-capita, per DA, within 15 mins (top) and 30 mins (bottom). Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023a), the Open Data Hamilton Portal (Hamilton, 2023a) and the USGS (USGS, 2010).~~

DAs are within the centre of Hamilton-Central, specifically for cycle- and walking populations. Policies that increase the number of available care-destinations within Hamilton-Central, improve conditions that decrease LICO-AT prevalence, as well as policies that make car-modes less spatial availability advantaged (i.e., encourage modal shift and decrease travel time) could be further investigated through the lens of mobility of care.

6. Discussion and conclusions

This paper is the first to conduct an exploratory ~~feminist~~ multimodal accessibility analysis of ~~care~~ Mobility of Care destinations – one that counters the current literature's emphasis on employment-related ~~travel~~destinations, a travel purpose more significant for men, and especially wealthy and educated men (Law, 1999; Hanson, 2010). Its aim is to challenge current planning paradigms by explicitly focusing on care ~~, vital and~~ destinations, locations that are vital for life-sustaining activities that are ~~undervalued, and to provide~~ currently undervalued. This study also provides a tangible example of how one could ~~gender-mainstream accessibility analyses~~ conduct gender-aware multimodal accessibility analyses using the City of Hamilton as a case study. In doing so, ~~it~~ this paper contributes to the emergent mobility of care literature, a body of what that has, to date, focused on quantifying this under-represented type of travel (Gómez-Varo et al., 2023; Murillo-Munar et al., 2023; Ravensbergen et al., 2022; Sánchez de Madariaga, 2013; Sánchez de Madariaga and Zucchini, 2019; Shuman et al., 2023) and ~~has provided~~ providing rich and nuanced qualitative accounts of lived experiences completing mobility of care (Orjuela and Schwanen, 2023; Ravensbergen et al., 2020; Sersli et al., 2020).

This ~~paper also contributes to accessibility research by implementing both an unconstrained (cumulative opportunities) and constrained (spatial availability) multimodal accessibility measure. The unconstrained~~ study also methodologically contributes to the accessibility literature by contrasting two multimodal accessibility measures: the widely used cumulative opportunities measure and the spatial availability measure, which offers accessibility insights on modal competition. The cumulative opportunities measure demonstrates the ~~potential interaction with~~ modal range of access by presenting the number of care destinations that each mode ~~offers from each DA~~ can reach within a 15- and 30- minute travel time ~~thresholds. The constrained measure incorporates the assumed proportion~~ threshold from each spatial location. Spatial availability constrains the cumulative opportunities measure by incorporating the *assumed* proportions of mode-using ~~population~~ populations and mode-specific travel ~~time to demonstrate the potential interaction with destinations that each DA has available to a~~ times; this yields the number of care destinations that the mode-using population ~~. The distinction between the constrained and unconstrained measures are clarified, namely that potential interaction may be over-inflated, especially for the lower range non-car modes, when considering unconstrained access over spatial availability. Unconstrained access may demonstrate over-inflated promise for active transport modes. The consideration of both unconstrained and constrained access can encourage a shift in perspective. Motorists are generally estimated high unconstrained access to many care destinations~~ has access to out of all care destinations in the study region. The two measures communicate different insights about the case study: the study's results demonstrate that the car mode offers high cumulative opportunities access as well as exceptionally high spatial availability ~~. Those who use alternative modes , have low unconstrained access~~ for motorists. While sustainable modes offer lower cumulative opportunities access (though higher in the city center) and, in certain ~~DAs, and even lower level of availability . This is as a result of car-using populations being allocated a disproportionate number of total care destinations . Spatial Availability is a way of conceptualising accessibility as a city-wide total and each calculated value is a proportion so it can be easily placed relative to all others in the city. However, it~~ areas, even lower spatial availability due to the disproportionately high spatial availability for the car users. In this way, relying only on the cumulative opportunities measure provides an incomplete picture, as it does not reflect how the relatively large quantity of motorists and the greater range offered by the car can disproportionately claim more care destinations than non-car modes (pedestrians, cyclists, and transit) users. Although spatial availability offers a more complex picture of how modes provide access under competition, spatial availability like other competitive measures, relies on assumptions ~~on~~ about who is "demanding" ~~the destinations , and how~~ destinations and by how much. How those assumptions are made are a subject of ongoing discussion in ~~how accessibility considers competition~~ the competitive accessibility literature (Merlin and Hu, 2017; Kelobonye et al., 2020).

Further, this study contributes to the literature on ~~sustainable travel behaviour. Results indicate that care is most easily accessed in Hamiltonby car, an unsurprising result given its car-oriented design~~equitable and sustainable transportation planning by providing a methodology to identify areas in need for further development. By highlighting how the car offers all-round high access and even higher spatial availability to care destinations in Hamilton, sustainable modes can be prioritized equitably. Previous research ~~has found that mobility of care~~ suggests that currently care trips are more frequently completed by car ~~or by foot~~ than by transit or ~~by bicycle (Ravensbergen et al., 2022) . It is possible that the car's ability to provide higher access to care destinations, as observed in this study, shapes this tendency to complete care trips by car. Car use may also be more frequent for care trips because these trips tend to~~ bicycle (Ravensbergen et al., 2022) as they often involve carrying things (e.g., groceries) or people (e.g., children). ~~Indeed, past qualitative work has found that many prefer travelling by car for this type of trip due to~~ Qualitative work supports this preference, citing convenience and increased safety ~~(Maciejewska and Miralles-Guasch, 2019; Carver et al., 2013). Then again, care trips tend to be shorter than other trips (Ravensbergen et al., 2022), making them ideal for more sustainable travel modes, such as active modes (walking, cycling) and public transport. The low access to care by foot identified in this study is discouraging, given both people's tendency to use this mode for care trips(Ravensbergen et al., 2022), and the benefits of walking as a travel mode, both for individuals, cities, and the environment. Somewhat unexpectedly, access to care was found to be low by transit and by foot and relatively high by bicycle. Given that low income women, in particular, seem to be transit reliant~~ as key reasons for choosing travel by car for care trips (Maciejewska and Miralles-Guasch, 2019; Carver et al., 2013) .

However, this study also highlights that the high spatial availability of motorists results in disproportionately low spatial availability for sustainable mode users, even in Hamilton-Central. While sustainability policies should aim to re-balance the spatial availability away from motorists to users of sustainable modes, these policies should incorporate an equity perspective that considers existing preferences in care trips. This study provides the stepping stones for such an equity lens in Figure 6, by presenting a cross-tabulation of areas with high LICO prevalence and low spatial availability per sustainable-mode that could be the focus of policy intervention. Consider the cycling plot in Figure 6, a factor driving the higher quantity of yellow DAs is the low proportion of cyclists assumed. This assumption holds in other Canadian contexts, cycling as a mode for care trips ~~(Ravensbergen et al., 2022), this result highlights both a potential bias against care trips by transit and the equity implications of that bias. Though past work has found that many barriers exist for~~ is also uncommon as cycling is uncommon (Ravensbergen et al., 2022) . Moreover, as care trips tend to be preformed by women, the low proportion of cycling for care ~~(Ravensbergen et al., 2020; Ravensbergen et al.; Sersli et al., 2020), the results of this study highlight the great potential of the bicycle for easily accessing care.~~ trips has been put forth as a hypothesis to explain the gender-gap in cycling observed in low-cycling cities (like Hamilton) where only a third of cyclists are women (Ravensbergen et al.; Prati, 2018). However, cycling as a mode has potential as it demonstrates high cumulative opportunities values. However, that potential is not being realized in part due to the low proportion of cyclists and the higher spatial availability values of motorists. Future research could examine what barriers those who conduct care trips are facing in regards to cycling, particularly focusing on the yellow areas indicated Figure 6.

~~The preliminary nature of this research also comes with its limitations as a result of data availability. The accessibility results are not calibrated to reflect observed mobility-to-care travel behaviour due to data unavailability nor are they formulated to express any normative accessibility goals. Instead, they present a preliminary exploration of how the mobility of care concept could be operationalised within accessibility analysis.~~

~~First, the travel time estimations assume free-flow network conditions: while impacting~~

6.1. Study limitations

This study presents three types of limitations related to assumptions in the accessibility measure methods and data availability. First, since travel times from origin to care destination are unknown, they are estimated assuming a road network under free-flow conditions. While this affects the estimated travel times, ~~estimated~~ research suggest that considering congested conditions may not ~~have a drastic impact on spatial accessibility calculations (Yiannakoulias et al., 2013), especially for cycling and walking modes~~significantly impact the resulting accessibility values (Yiannakoulias et al., 2013). In the context of Hamilton, congestion is also pertinent to car and transit modes, and not for pedestrians or cyclists (their travel infrastructure). Second, ~~the use of a binary travel time cut-off~~ using a binary impedance function instead of a more complex ~~travel impedance function can have a significant impact on accessibility results . To add reliability, two literature-informed travel cost thresholds (15-minutes and 30-minutes) were selected, but results' interpretation are hampered by the binary function selection: some zonal populations could *still* value~~ distance-decay function could significantly affect accessibility results (Kapatsila et al.). For instance, destinations beyond a 30-minute travel time ~~, and some populations may not see a destination~~ could still be valued by people, and those within 5 ~~minutes~~ and 15 minutes ~~away as necessarily equal in travel impedance .~~ do not necessarily have the same importance. However, the use of the binary impedance function trades complexity for interpretation, and this trade-off was made strategically made to improve interpretability and compare the two accessibility measures. To enhance reliability, two literature-informed travel cost thresholds (15-minutes and 30-minutes) are selected. Third, the geometric centroids of DAs (origins) and destinations (all care destinations) were used as inputs for travel time calculations. ~~DAs are~~ This is a limitation as DAs were created for the purpose of the statistic census: they vary in area and their centroids may not necessarily align with where that population may begin their journey to care destinations. ~~Fourth, the quality, importance and specific willingness to travel to types of care destinations for mode-using populations within a zone was not considered as data is unavailable city-wide. As such~~This methodological decision presents limitations on how the travel time estimates can be interpreted to reflect actual travel times to care destinations.

Moreover, due to the exploratory nature of this research and novelty of the Mobility of Care concept, no research to date has directly captured the characteristics of mobility of care trips in Hamilton. The presented results thus are not calibrated to reflect observed mobility of care travel behaviour nor establish normative accessibility goals (Páez et al.). Travel behaviour data is needed to calibrate local destination-specific travel impedance cutoffs (e.g., using a 15 minute cutoff for grocery-centric destinations and 30 minute cutoff for health-centric destinations) or assigning weights for each destination type as done in previous studies (e.g., a weight that reflects their 'capacity' (Li and Wang, 2024) or their 'attractiveness' using origin-destination flows from travel surveys (Graells-Garrido et al., 2021; Cheng et al., 2019)). In absence of travel behaviour data, this study ~~assumes~~ uses uniform travel time thresholds for all destinations and no destination weights are applied. This limits the result's interpretation to the *potential* to access *all* care destinations within 15- or 30- minutes, it does not include the real individual socio-economic and intersectional characteristics that influence what destinations can be potentially accessed. Consequently, each destination is ~~1 opportunityand re-weights each of the five care categories to be conceptually equal . Fifth, the mode choice for care destinations trips is unknown and hampers interpretation of spatial availability . It is assumed in the study to be equal to the work-commute mode selection, but this is~~ treated as a single opportunity, e.g., a school, a clinic, a hospital, and a grocery store are all equal to one opportunity each. Additionally, since care trip modal choice is unavailable at a disaggregated level for Hamilton, the commute mode choice is assumed for the spatial availability measure. This mode may not be ~~necessarily the case~~what is used to visit care destinations and hence places an limitation on how the results should be interpreted.

Taken together, the discussion of these limitations present room for future research to incorporate context-specific mobility of care travel surveys into accessibility analysis to more accurately reflect mobility of care accessibility landscapes. Future work could ~~look to address these limitations as well as compare~~ also look to disaggregate access to care by category and compare results to conventional access to work landscapes. This comparison could highlight the bias in planning towards jobs as well as substantiate equity critiques.

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Report to reviewers regarding the revised "Exploring mobility of care with measures of accessibility" Journal of Transport Geography manuscript

We'd like to sincerely thank the editor for the opportunity to revise and re-submit our manuscript now titled "Exploring Mobility of Care with measures of Accessibility": We would also like to thank the reviewers for their insightful feedback on the manuscript. The revised manuscript has been extensively edited to incorporate all suggestions, which we believe has improved the clarity of the paper's objective, methods, results, and discussion. The following points are a summary of the changes you'll notice throughout the revised manuscript, and the next three sections provide detailed replies to each comment from each reviewer. Reviewers' original text is in black and our replies are in blue. Again, thank you for your dedication in providing feedback.

- The title of the manuscript has been changed from "Exploring mobility of care with measures of access: a case for gender-mainstreaming accessibility analysis", to "Exploring mobility of care with measures of accessibility".
    - The gender-mainstreaming perspective provided by Mobility of Care is now explained in text, therefore we were able to shorten the title to enhance clarity.
- The Introduction, Methods (where population data is detailed), and the Discussion and Conclusion sections now all mention the importance of considering low-income status in Mobility of Care research.
- The paper's objectives are clearly stated at the end of the last paragraph in the Introduction section.
- A short multimodal accessibility review section is added, following the Introduction section. This is to clarify the destination and mode focus of multimodal accessibility measures (both cumulative and accessibility measures that consider competition) and demonstrate how the consideration of multimodal access to Mobility of Care destinations is novel and the consideration of competition effects is complimentary to accessibility interpretation.
- We added more information about transit, walk, and bike infrastructure in Hamilton – in the Background section (particularly, see the enhanced Figure 1 which now includes the density of bus stops as well as bike/walk infrastructure).
- Added additional context on how care destination categories were decided on in the Destination Dataset subsection of the Background section.
- Added additional explanation on why LICO and All Populations are relevant to Mobility of Care to the Background section in Population subsection.
- Separated the accessibility methods from the original Background and Methods section. Now, the literature on Accessibility Measures (section) is reviewed, then Background on Hamilton (section) data is explained, then the Accessibility Measures (section) used are detailed.
- Removed the care category weighting scheme and its associated description in the methods and added a short discussion on how weights could be added based on a Mobility of Care travel survey to the Discussion and Conclusions section.
- Reshaped and largely rewrote the Results section – see the new and improved Figures within, e.g., Figure 5 now demonstrates both measures for all four modes and 15-minute and 30-minute travel thresholds.
- Reshaped the Discussion and Conclusions section to make the discussion of the results and the paper's contribution clearer. Also added a 'Limitations' subsection to separate the results, discussions, and paper conclusions from the study's limitations.

Reviewer #1:

This is an interesting manuscript on care accessibility. The author(s) intends to contribute in the field of mobility of care as a gender-mainstreaming analysis with empirical focus on Hamilton, a Canadian City. I regard the topic approached as important for the Journal of Transport Geography. However, there are various confusing parts in the text, while some key pieces of information are missing. I suggest the author(s) to address the following in a revised version:

1. Overall, the main issue of this manuscript is how it is framed. It is said that the manuscript´s main aim is to perform a "gender-mainstreaming accessibility analysis". The resulting analysis is, however, far more modest. The author(s) perform an analysis of care accessibility in Hamilton; they did not bring any gender-related analysis. The author(s) rely on the trip purpose to link the analysis to a gendered perspective. The fact that more women perform care trips does not mean that analyzing care trips include analyzing gendered trips. Especially, the use of the term "gender-mainstreaming" accessibility confuses me in the title; before reading the manuscript, I had the expectation to find a gender-related analysis. Nevertheless, it is fair to say that author(s) may have come to the scope of analysis motivated by gendered results from the literature. I believe that this needs to be re-defined.

Thank you for this raising this important point on the gendered framing of the manuscript. Indeed, you are right to point out that our analysis is more 'gender-motivated' than a 'gendered analysis' as we adopt the Mobility of Care concept. We were happy to reframe our analysis more accurately. To ward off misperceptions - first and foremost, the term "Gender-Mainstreaming"[1] should have been explicitly defined, so we've renamed the manuscript, now "Exploring mobility of care with measures of accessibility".

Further, though we believe our manuscript offers an approach that can be part of gender-mainstreaming policies in transportation planning, we understand there are many dimensions to transportation planning that accessibility analysis is outside the scope of. Often accessibility analysis is not observed or forecasted travel, its about *potential* travel to some destinations: the trip purpose. "How many **jobs** opportunities can one reach within a given time period?" is a question accessibility analysis can estimate, and usually has. But our paper asks, why the focus on jobs? While jobs can be important for all people, they are not the only destination that can be important for all people. In fact, care trips (i.e., travel to destinations that are non-paid and essential for household maintenance) make up a significant destination purpose in people's daily lives. This is particularly the case for women, and lower-income women (Ravensbergen, 2022). We argue this myopic focus on employment destinations rooted in a masculinist tradition in planning, such as the data that is available (i.e., what is chosen to be collected) is often employment focused allowing the proliferation of the status quo – this is part of this story. Since care destinations are relatively understudied (compared to employment destinations), and absent from the accessibility literature, this manuscript aims to provide a case for this 'gender-mainstreamed' accessibility analysis.

In addition to the title-change, we've made this more nuanced framing clearer throughout the manuscript, we've replaced "Gender-Mainstreaming" with "Gender-Aware", as the Mobility of Care framework is just that: gender-aware. As defined by Ines Sanchez de Madariaga, "*The umbrella concept "mobility of care" provides a framework for recognizing, measuring, making visible, valuing and properly accounting for all the travel associated to those caring and home related tasks needed for the reproduction of life. While these daily tasks continue to be mostly performed by women around the world, as men increase their participation in care activities, gender approaches to transport planning will become more and more significant for individuals of both sexes. The aim is to build a better knowledge base of mobility patterns, behaviors and needs on which to develop more equitable transport policies that provide a better response to gender needs to the benefit of both men and women.*"[2]. Part of Sanchez de Madariaga's proposals for addressing the issue

[1] As defined by the European institute for Gender Equality, gender-mainstreaming is a policymaking approach that accounts all gender's interests and concerns to achieve gender equality. Source : https://eige.europa.eu/gender-mainstreaming/what-is-gender-mainstreaming?language_content_entity=en#:~:text=Gender%20mainstreaming%20is%20not%20a,growth%2C%20employment%20and%20social%20cohesion.

[2] Source : https://unhabitat.org/mobility-of-care-ines-sanchez-de-madariaga

are to explain the concept and demonstrate measurement methods. This manuscript answers this call in the flavour of an accessibility measure: a comparison between a commonly used accessibility measure (cumulative opportunities) by researchers and practitioners alike and a new accessibility measure that considers competition. The comparison of the measures is useful, but we believe it is particularly impactful as the comparison foregrounds care destinations, their neglect in the literature, and the potential impact on those who reside in lower accessibility neighbourhoods.

Given this, we've reworked the abstract and manuscript to hopefully ward off misperceptions and more accurately capture the manuscript's contributions. Again, thank you for raising this important point regarding the framing!

2. In the first line of the conclusion, the author(s) claim to have conducted the first "exploratory feminist accessibility analysis of care destinations". The author(s) mention "feminist" without first introducing (not to mention discussing) the term. The information that women perform more care-related trips is far from the conclusion that analyzing care trips is a feminist-oriented solution. Feminism is a much complex theme that would need more space to be addressed. Moreover, the manuscript dos not discuss the gendered participation in care responsibilities, or the female travel pattern discussed in the literature.

Thank you for raising another great point. In line with your first comment, our scope was motivated by Gender Equality – specifically within the Mobility of Care framework which our Introduction section introduces. This topic is inherently linked to feminist approaches. However, you're completely correct – feminism is a complex topic. We do not have space (within the word limit) to sufficiently address it along with the paper's objective. Therefore, we've removed mentions of 'feminist' and replaced it with 'gender-sensitive'. This is also a more accurate framing of what was done, and we thank you for noting this. The first line of the Conclusion section also now reads:

> *"This paper is the first to conduct an exploratory multimodal accessibility analysis of Mobility of Care destinations – one that counters the current literature's emphasis on employment-related destinations, a travel purpose more significant for men, and especially wealthy and educated men".*

Together with the first comment, we've re-worked the Introduction and Discussion and Conclusions sections to further clarify this point. We hope the revised manuscript addresses these concerns.

3. Interestingly, the manuscript includes a socioeconomic information in the analysis, with income data of the neighborhoods. For me, however, this was a surprise during the text, once socioeconomic aspects do not appear sufficiently in the introduction, and should do. Especially for this perspective, the manuscript should inform if all schools were considered equally, both public and private ones. Same for hospitals, health-related destinations, recreation centers, senior centers, and so on. Can they be used by all socioeconomic range, or are there limitations for low-income inhabitants?

Topics that are missing in the introduction to support and enrich this perspective are listed below:
a. An intersectional perspective, especially between gender and socioeconomic status;
b. A gendered modal division, regarding socioeconomic perspective, such as the ownership of a car.

Excellent points regarding how the intersection between low-income and 1) destination type and 2) mode-use, should be further clarified.

Regarding 3.a., we added this perspective to the Introduction section, Background on Hamilton Section, and Discussion and Conclusions.

- The Introduction now introduces a few more references discussing the intersection of low-income status and gender. This discussion was present in the original version, but perhaps insufficiently. Thank you for this comment, see the revised text:

  Further, the current under-reporting of mobility of care in research and planning has important equity considerations. Not only are mobility of care trips completed predominantly by women, this gendered discrepancy is greater in low-income households [Murillo, 2023; Sanchez de Madariaga, 2013; Ravensbergen, 2022]. For instance, in lower income households in the city of Montréal, women complete 50% more care trips than men [Ravensbergen, 2022]. The power of the Mobility of Care concept lies in its ability to highlight the masculinist bias in transport research – travel for care appears insignificant because travel surveys are not written to capture it [Sanchez de Madariaga, 2013].

- We also added mention that all destinations are public, with exception to some of the senior centers, to the "Care destination dataset" subsection in "Background on Hamilton" section":

  The majority of destinations included can be publicly accessed (e.g., only public schools, grocery stores, clinics, community centres). However, certain destinations may require a fee that could be prohibitive for lower-income households (e.g., all long-term care homes, whether publicly subsided or private are included).

- In the Discussion and Conclusions "Study Limitations" subsection, regarding the absence of mobility of care travel behaviour for Hamilton, we add a disclosure on how the results should be interpreted. Of note: we removed the destination weighting scheme all together, as it is simpler and more accurate to keep the destinations unweighted and leave room for accurately calibrated weighting that considers individual-level Mobility of Care travel behaviour, when that becomes available.

  "Absence of mobility of care travel behaviour, lack of capacities or attractiveness characteristics for destinations, and the mode used to access destinations in Hamilton presents limitations" on how the results should be interpreted… *"In absence of this data, destinations are left unweighted, limiting result interpretation to the _potential_ to access all care destinations, instead of including the real individual socio-economic and intersectional characteristics that influence what destinations can be potentially accessed. In other words, each location is considered as simply one opportunity, e.g., a school, a clinic, a hospital, and a grocery store are all equal to one opportunity each."*

Regarding 3.b, the Introduction, Discussion and Conclusion sections are enhanced with a refined focus of the gendered modal division in addition to sustainability.

> Introduction: *"Care trips are also less likely to be completed by public transit or bicycle [Ravensbergen, 2022] and are more likely done by car or foot than the commute [Maciejewska, 2019; Ravensbergen, 2022]. One way to apply a gender-aware lens to accessibility analysis is by explicitly considering access to destinations involved in Mobility of Care by multiple modes. Reframing accessibility analysis in this way reinforces its importance as an instrument that supports the planning of sustainable and equitable travel and land-use in cities."*
>
> Discussion and Conclusion: *"Results demonstrate that the car offers all-round high access to care destinations in Hamilton, an expected result given the city's car-oriented design. However, previous research suggests that care trips are more frequently completed by car than by transit or bicycle*

[Ravensbergen, 2022]. Care trips tend to involve carrying things (e.g., groceries) or people (e.g., children), aligning with qualitative work that found many prefer travelling by car for this type of trip due to convenience and increased safety [Maciejewska, 2019; Carver, 2013]. Hence, targeted policy that reduces car accessibility or the spatial availability of car-users should be adopted from an equity perspective that considers preferences in care trips, especially those of lower-income households."

4. In the methodology, the author(s) present a comparison between unconstrained and constrained multimodal accessibility. The destinations were grouped into five care categories. Is there any reference from the literature to support this choice of groups? If not, please explain to better support your assumption. For the Health-centric category, the author(s) included both hospitals and clinics with pharmacies; In this group, a care service is mixed with a commercial distribution related to care. This combination can camouflage the results for the health care service accessibility. Furthermore, as I understood, a high-complexity hospital is counted equally to a small pharmacy, especially for the cumulative accessibility this is a concern; is this understanding correct? This issue must be addressed or explained.

Great points. We've addressed this comment in two ways, first by improving the explanation of how the categories were generated (In Care destination dataset subsection) and second by removing the weighting scheme (Accessibility methods section) and expanding the study's limitation subsection in the Discussion and Conclusions.

First, the category explanation. We adapted categories based on the travel survey conducted by Sanchez and Zucchini (2019) (for Madrid), which is the only study that directly measures mobility of care. Specifically, they capture two main categories "childcare" and "Attention to other dependent individuals":

Childcare • Escorting to: 1. School 2. Nursery 3. Other activity (social: e.g. Playground, …) 4. More frequently used services (Doctor, Pharmacy, …) 5. Other Services (Library, Shopping, ...) 6. Employment 7. Strolling • Activity for children: 1. School 2. Shopping 3. Visit 4. Turn Around 5. Primary Services (Hospital, Pharmacy, ...) 6. Other activities (preparing meals, homework…)	Attention to other dependent individuals (e.g. parents, relatives or someone else not a family member) • Escorting to: 1. Shopping 2. Other activity (Social, Religious…) 3. Services (Hospital, Pharmacy, ...) 4. Strolling 5. Errand • Activity performed for other individuals: 1. Visit 2. Shopping 3. Pick up/Drop off 4. Errand 5. More frequently used services (Doctor, Pharmacy, ...) 6. Other activities (preparing meals, house cleaning, ...)

This survey emphasises trip purpose while our analysis is one of potential interactions with destination places outside the private sphere (i.e., the end point of a trip purpose in the public sphere). Trip purposes overlap with destinations, so we did our best to generate the care task categories we interpreted from Sanchez and Zucchini (2019) and tie them into distinct types of destinations. The care task categories are:

- Caring for children (most of the Childcare destination types resulting from Sanchez and Zucchini (2019). Called "Child-centric" in the study and relate to destinations like schools, daycares, and community centres, recreation centres, and parks),
- caring for elders (most of the Other Dependent destination types resulting from Sanchez and Zucchini (2019). Called "Elder-centric" in the study, includes destinations like Senior centres, long-term care homes, and retirement homes – namely, places that are not typically meant for children, that's how this category was determined)
- caring for health (this could apply to caring for children or for elders, it also applies to ones on self maintenance. Called "Heath-centric" in the study, it includes Hospitals, pharmacies, clinics, and dentist offices).
- household maintenance: which includes grocery shopping and errands. Both tasks are important to the household but different, so we split this task into:
    - caring for household maintenance errand ("Errand-centric" including Libraries, post offices, and banks)
    - caring for household maintenance grocery ("Grocery-centric" including all locations that sell groceries)

To reiterate, destinations and trip purposes are not the same thing. Destinations often can receive multiple trip purposes, and a type of trip purpose can land you at different types of destinations. We tried our best to work from Sanchez and Zucchini (2019)'s categories to generate new categories that are more conceptually congruent for an accessibility analysis. We added a few sentences to the methods to clarify this thought process:

> *" To showcase the dataset, it is grouped by care destination category. These five categories were generated by the authors following the travel purpose categories created in the mobility of care research by (Sanchez de Madariaga, 2019). Notably: child-centric (destinations for "Childcare" escorting trips), elder-centric (common destinations for other escorting trips that are not childcare-focused), grocery-centric, health-centric, and errand-centric destinations."*

Second the weighting scheme: In our original manuscript, we incorporated a generalized weighting classification that would make each destination within a category equal, and the category equal to all other categories. We did this assuming, theoretically, all categories are equally important. But in reality, we do not know if this is true; we would need a survey like the one conducted by Sanchez and Zucchini (2019) but for Hamilton, to calibrate the weights. However, it presented an opportunity to demonstrate how one *could* weight the destinations.

However, as you correctly point out, all types of destinations within a category are not equivalent (a healthcare clinic is not likely equal to a hospital), nor arguably are all categories equal to each other. For this reason, we've decided to take a simpler approach: we've revised the manuscript to exclude this weighting scheme all together. We've also added the important question of travel behaviour to destination types into the "Limitations" subsection of the Discussion and Conclusions:

> *"Absence of mobility of care travel behaviour, lack of capacities or attractiveness characteristics for destinations, and the mode used to access destinations in Hamilton presents limitations as well. Accessibility literature has weighted destinations (amenities) using a variety of method such as estimated capacity of destinations [Li, 2024] or origin-destination flows from travel surveys indicating attractiveness of certain destination types [Graells, 2021; Cheng, 2019]. However, traditional 'capacities' like health care facilities have beds is not relevant for all care destinations, moreover, origin-destination flows to all care destinations also have not been counted within the region's travel survey (e.g., TTS [TTS, 2018]). In absence of this data, destinations are left unweighted, limiting result interpretation to the _potential_ to access all care destinations, instead*

> *of including the real individual socio-economic and intersectional characteristics that influence what destinations can be potentially accessed. In other words, each location is considered as simply one opportunity, e.g., a school, a clinic, a hospital, and a grocery store are all equal to one opportunity each. Furthermore, the aggregated mode choice for mobility of care trips in Hamilton is unknown and hampers interpretation of spatial availability results. In this study, mode choice is assumed to be equal to the work-commute mode selection, but this is may not be necessarily the case. These limitations present room for future work to incorporate context-specific Mobility of Care travel surveys into accessibility analysis to more accurately reflect care trip travel behaviour."*

5. After grouping the care destinations, I had expectations to see the accessibility for each group. Instead of that, the author(s) presented only the accessibility for the groups together. Then I suggest the comparison of the accessibility for each group separately, in order to enrich the conclusions, and possible contributions to public policies.

This is a fantastic suggestion; however we're concerned with implementing it due to the exploratory nature of this work – we do not know the population's preferences for mode-choice for care destination type in the Hamilton context (we assume mode-choice to work for the spatial availability measure), so disaggregating results by care destination category may be misleading for the spatial availability measure. This paper is also framed by the Mobility of Care concept which argues that care trips should not be separated, as doing so can hide their significance in daily mobility (for instance, trips to grocery stores on their own are infrequent, but combined with all other care trips they make up almost a third of adults' trips). Separating all these destinations out risks undermining the mobility of care concept. We have not added to the analysis, but we have made it clearer that these categories are used to showcase the data in the Care destination dataset subsection:

> *"A novel geospatial dataset of care destinations for Hamilton was compiled using a variety of local sources and manually confirmed through Google Maps. As a way to showcase the dataset, it is grouped by care destination category.*

Further, if you still disagree, perhaps we can add these disaggregated analyses in an appendix in a future submission? We would be happy to do so, though hesitate for the reasons specified.

6. Regarding the transportation infrastructure of Hamilton, the following overall information is relevant and I think it should be added:

a. How is the public transportation system in Hamilton? What was considered as transit - Buses, only? Are there other systems included?

b. How is the bike infrastructure in Hamilton? Are there segregated Bike lanes? How was that considered for the accessibility: was cycling considered sharing space with motorized transport? Please, clarify this in the manuscript.

Excellent suggestion to provide more clarity to the transportation infrastructure of Hamilton. We've enhanced Figure 1 to now visualise the density of transit stops and walking and cycling infrastructure in Hamilton, with some additional details regarding the infrastructure. We hope we achieved a balance between detail and the Journal's word limit.

Regarding 6.a public transportation system in Hamilton, and 6.b. bike infrastructure in Hamilton in the Background on Hamilton section:

> "*Hamilton is divided into six regional communities (@fig-Fig1). Hamilton-Central is the most urbanized of the six, and the five periphery communities of Dundas, Ancaster, Flamborough, Glanbrook and Stoney Creek are significantly more suburbanized with the furthest periphery regions being undeveloped or rural owing to their inclusion in the region's greenbelt [@Greenbelt Foundation, 2023]. These different urban forms and associated transport infrastructure play a key role in access to care destinations. Hamilton Street Railway (HSR) is the city's transit provider operating only buses at the current date. Notably, Hamilton-Central is the only community fully serviced by HSR and has the highest concentration of walking and bike infrastructure for mainstream use (e.g., Level of Traffic Stress 1 or 2 which indicates low-speed, low-volume streets, separated bicycle facilities, and dedicated lanes where cyclist must interact with traffic at formal crossings) [Conveyal, 2024] as identified in the OpenStreetMaps road network [Geofabrik, 2023] and the city's General Transit Feed Specification file [Transitfeeds, 2023].*"

7. Regarding the modal division, one finding of the manuscript is that access to care is "relatively high by bicycle", and "highlight the great potential of the bicycle for easily accessing care". The gendered modal split pattern, which can be found in the literature, can enrich this discussion. Wide literature has found that women cycle less than men, especially when the infrastructure is absent.

Excellent point. We had addressed the potential for cycling to be used for mobility of care in the Discussion and Conclusions:

> *"However, this study also highlights that the high spatial availability of motorists results in disproportionately low spatial availability for sustainable mode users, even in Hamilton-Central. While sustainability policies should aim to re-balance the spatial availability away from motorists to users of sustainable modes, these policies should incorporate an equity perspective that considers existing preferences in care trips. This study provides the stepping stones for such an equity lens in @fig-Fig6, by presenting a cross-tabulation of areas with high LICO prevalence and low spatial availability per sustainable-mode that could be the focus of policy intervention. Consider the cycling plot in @fig-Fig6, a factor driving the higher quantity of yellow DAs is the low proportion of cyclists assumed. This assumption holds in other Canadian contexts, cycling as a mode for care trips is also uncommon as cycling is uncommon (Ravensbergen, Fournier, & El-Geniedy, 2022). Moreover, as care trips tend to be preformed by women, the low proportion of cycling for care trips has been put forth as a hypothesis to explain the gender-gap in cycling observed in low-cycling cities (like Hamilton) where only a third of cyclists are women (Prati, 2018; Ravensbergen, Buliung, & Laliberte, 2019). However, cycling as a mode has potential as it demonstrates high cumulative opportunities values. However, that potential is not being realized in part due to the low proportion of cyclists and the higher spatial availability values of motorists. Future research could examine what barriers those who conduct care trips are facing in regards to cycling, particularly focusing on the yellow areas indicated @fig-Fig6."*

Reviewer #2:
Author has collected dataset regarding care trips,and did an interesting analysis. The outcomes of this investigation seems valid and useful.

Review findings:

1. The background and literature section is appropriate.

Thank you!

2. The objectives should be stated more clearly in the introduction section.

Great organization point. We’ve amended the last paragraph of the Introduction section to state the study’s objectives more clearly.

> *“Taken together, this study's objective is to contribute to the transport planning literature through the demonstration of a multimodal accessibility analysis of Mobility of Care destinations. Two accessibility measures are used: the cumulative opportunity measure and the singly-constrained spatial availability measure. The measures are applied on a care destination dataset with novel Mobility of Care classifications for the city of Hamilton, Canada. The potential access to Mobility of Care destinations for walking, transit, bike, and on foot is calculated for 15- and 30-minute travel time thresholds. Results are compared across the two measures and four modes, and the overlap between low accessibility areas and high low-income prevalence is presented. Implications of the results are discussed along with study conclusions.”*

3. The methods are explained with details in the Section, "Background and methods." However, the tools and techniques used in the investigation should be reflected in the Abstract also.

Great point. The abstract has been modified to highlight what methods and techniques were used in the manuscript. We believe the revised abstract is clearer on this matter.

> *“Accessibility, the ease of interacting with potential opportunities, is an increasingly important tool amongst transport planners aiming to foster equitable and sustainable cities. However, in accessibility research there is a historical focus on employment destinations that is shaped by a masculinist transportation planning tradition. This paper aims to counter this gendered bias by connecting the Mobility of Care framework, a gender-aware transport planning conceptualisation to an empirical accessibility analysis of care destinations in the City of Hamilton, Canada. Care destinations are all the places one must visit to sustain household needs such shopping, errands, and caring for others (children and other dependents). Through the creation of a novel care destination dataset, this paper considers access to care across different modes of transport at two travel time thresholds (trips shorter than 15-minutes and 30-minutes). The methods include using a routinely used accessibility measure (cumulative opportunity) and a novel competitive and singly-constrained accessibility measure (spatial availability). Results indicate that accessibility to care destinations by car is exceptionally high, and access by public transit, cycling and by foot is low across the city with some exceptions in the inner city. Notably, there are distinctions between both methods: cumulative opportunities illustrate a more optimistic potential interaction landscape for non-car modes, while the spatial availability measure demonstrates a theoretically more realistic spatial distribution of care destination availability of potential interaction. Neighbourhoods with both low spatial availability to care and a high proportion of low-income households are also identified as areas in need of intervention. The manuscript and analysis are computationally reproducible and openly available. The analysis presented demonstrates methods planners can use to apply a gender-aware lens to accessibility analysis. Further, results can inform policies aiming to encourage sustainable mobility.”*

4. Author may add the validation of finding using statistical methods.

Good point, however, unfortunately the analysis is descriptive and exploratory in nature: it represents the potential care opportunities that *could* be accessed and are spatially available to the mode-using populations. However, it does not include travel behaviour characteristics that reflect individual's travel to care destinations as this data is not typically collected within traditional travel surveys. Furthermore, validating access to all care destinations – as their diversity of uses are numerous – is challenging with limited data. E.g., even if we did have neighbourhood level school enrollment data and we demonstrate a significant relationship to accessibility, this does not represent _all_ care destinations. From this perspective then, we limit our scope to be exploratory and descriptive in nature: we do not demonstrate that our accessibility maps relate to actual mobility of care travel behaviour, we instead demonstrate the potential interaction with care destinations (of which actual interaction is a subset). Hopefully this answer addresses this general comment, but please let us know if you had specific ideas in mind that fit within the objective and scope of the manuscript.

Reviewer #3:

The article proposes and applies a methodology to measure the accessibility of strategic 'mobility of care' points to avoid some masculinity biases in common accessibility studies. The study topic is timely and worth investigating, but it needs to be reviewed and improved for publication.

First, the writing needs revision. Check typos and English; in some parts, it is difficult to read from the initial state of the art. This section is difficult to follow.

Thank you for this comment. We've heavily revised the manuscript, particularly focusing on clarity. We believe the revised manuscript has been largely improved.

I think the structure of the paper needs to be revised to make the flow clearer. For example, I suggest separating the background and method first by making the method stand out from the application. You can use a diagram or flow chart at the beginning to clarify the procedure and help readers understand the content; then, afterwards, describe the case study. The structure now is too confusing. I also suggest splitting the discussion and conclusions. The latter should be shorter and include the main findings and implications.

Thank you for this excellent suggestion. Indeed, we've incorporated your ideas and believe the manuscript's flow has been greatly improved. Specifically, we added a short overview of accessibility methods (a short Literature Review, given the word limitations of the journal) after the Introduction section to bridge accessibility from the Intro to the third section in lieu of your suggestion to add a flow chart. We believe this addition is conceptually similar to your suggestion but may add more value to readers.

We then detail the case study in the third section, a "Data" section, with clear sub-headings. Then, we take your suggestion and include a stand alone Methods section as Section 4; detailing the cumulative opportunity measure first and then the spatial availability measure.

We chose to keep the Discussion and Conclusions section as is, due to the word limit of the Journal, but reorganized the text for clarity. The section starts with a short summary of the paper and follows with discussion points and a subsection titled "Study limitations" to bound the interpretation of the results and shed light on future research avenues.

Thank you for this crucial points, we believe the manuscript's flow has greatly improved.

Evaluate the position of figures that interrupt the reading too often. Furthermore, is it possible to find a representation to compare fig 5 and 6 without having to scroll back and forth in the text?

Excellent suggestion: see the Figure 5 which now displays the old Figure 5 and 6 in one single figure. Thank you for this, we believe it is now easier for readers to compare the two measures.

Other comments:

* Line 70 is unclear: destinations or multiple modes?

Good catch. This should be *"In this spirit, this study foregrounds the theoretical mobility of care concept by calculating the accessibility to care destinations ~~or~~ and multiple modes in an empirical case study of Hamilton, Canada."* We've corrected this in the revised manuscript.

* 74-80 rewrite because it is unclear, especially the description of spatial availability

Fair point, thank you. We've actually removed mention of competition effects in the introduction and now save that for Section 2 (the literature review). The study's objective (as stated at the end of the Introduction) now reads:

"Taken together, this study's objective is to contribute to the transport planning literature through the demonstration of a multimodal accessibility analysis of Mobility of Care destinations. Two accessibility measures are used: the cumulative opportunity measure and the singly-constrained spatial availability measure. The measures are applied on a care destination dataset with novel Mobility of Care classifications for the city of Hamilton, Canada. The potential access to Mobility of Care destinations for walking, transit, bike, and on foot is calculated for 15- and 30-minute travel time thresholds. Results are compared across the two measures and four modes, and the overlap between low accessibility areas and high low-income prevalence is presented. Implications of the results are discussed along with study conclusions."

And that sentence, now in Section 2, now simply reads: *"A critique leveled at cumulative opportunity measures (and other non-competitive accessibility measures) is its omission of competition-for-opportunities effects."*

* 82-85 Why use two different sources to describe Hamilton's population? Use more recent data

Hamilton is a city within the GTHA; the additional data sources are used to demonstrate the population size of the GTHA which is not in the Hamilton Population data citation. However, we've streamlined the citations to make this clearer. The text now reads:

"This paper focuses on Hamilton as a case study, a mid-size city of approximately 500,000 residents that lies within the urban and suburban Greater Toronto and Hamilton Area and is home to seven million people, or approximately 20% of the Canadian population [City of Toronto, 2022].

Hamilton is divided into six regional communities (@fig-Fig1). Hamilton-Central is the most urbanized of the six, and the five periphery communities of Dundas, Ancaster, Flamborough, Glanbrook and Stoney Creek are significantly more suburbanized with the furthest periphery regions being undeveloped or rural owing to their inclusion in the region's greenbelt [Greenbelt Foundation, 2023]. These different urban forms and associated transport infrastructure play a key role in access to care destinations…."

* point locations of origins is not clear to me what they are and how they were identified.

It is mentioned in the manuscript that the point locations of origins are the geometric centroids of the DA. We enhance the clarity in explanation in the text. Subsection in "Background on Hamilton" related to Travel times now reads:

"As empirical travel behaviour to care-oriented destinations is uncounted and thus travel time is unavailable, travel time is approximated. Travel times by walking, cycling, transit and car is calculated for the geometric centroids of the DAs to the geometric centroids of the care destination location using the 'travel_time_matrix()' function from the {r5r} package [Pereira, 2021]. Inputs are point locations of DA centroids (origins), care destinations centroids, an OpenStreetMap road network including bike, transit and vehicle infrastructure [Geofabrik, 2023], and city GTFS transit routes/schedules [Transitfeeds, 2023]."

For additional clarity in the Method, when describing the variables of Equation (1), i is defined as *"a set of origin locations (e.g., DA centroids)".*

Furthermore, the use of geometric centroids of DAs as origins is discussed as a study limitation in the Discussion and Conclusions section:

> *"Third, the geometric centroids of DAs (origins) and destinations (all care destinations) were used as inputs for travel time calculations. This is a limitation as DAs were created for the purpose of the statistic census: they vary in area and their centroids may not necessarily align with where that population may begin their journey to care destinations. This methodological decision presents limitations on how the travel time estimates can be interpreted to reflect actual travel times to care destinations.."*

* Line 206: is this an error 20.45, or is it correct? And * Lines 199-212 confusing

Nice catch, it was an error and this paragraph was rewritten. These sentences are now is included in the "Travel impedance function" subsection and reads:

> *"This selection is informed by a scan of the literature. Typically, literature considers travel to one type of care category (e.g., health, or school, or grocery stores) and each destination type is associated with different travel impedance behaviour (e.g., grocery shopping trips are on average 15 minutes [Hamrick and Hopkins, 2012], trips to receive cancer treatments are on average 20 minutes [Segel and Lengerich, 2020]. In other care-related accessibility analyses, travel time thresholds of include 10 mins (for daycares) [Fransen, 2015] and 30 mins to 1 hr (for hospitals) [Schuurman, l2006] are selected. Of the one study to-date that has calculated the average travel times to all different categories of care destinations, travel times to each care category differ by mode e.g., 16 minutes by car and 36 minutes by public transport [Ravensbergen, 2022]. To broadly reflect this past research: 15 and 30 minutes are selected."*

* Line 258 "Consider cycling: the access" re-write without ":"

This section was re-organized, and the use of the colon has been removed from this sentence. The full paragraph now reads:

> *"The cumulative opportunity access is insightful in illustrating the range in which opportunities can be accessed by each mode based on their travel speed (on available infrastructure), a summary of each origins' modal opportunity isochrone. However, the cumulative opportunity measure does not account for competition effects. Namely, what proportion of the modal opportunity range is _spatially available_ to a mode-user at a given location when competing for those same opportunities with other mode-users. Considering competition in this way conjures richer conclusions that reflects the mode-using population. For instance, consider cycling, a mode that offers a relatively high range but still smaller than the car. The cumulative opportunity values in @fig-Fig5 reflects this intuition: Q3 and Q4 cumulative opportunity values are present for cycling in Hamilton-Central, offering the second-best cumulative opportunity access after the car. However, bike spatial availability values depict a more complex story of opportunity accessibility: it reflects the mode's opportunity range as well as proportion of mode-using population and how their range relatively compares to all other modes. The bike-using population is small (2% of the population), with many DAs having no or low proportions of bike-users. Meaning DAs with no bike-users are proportionally allocated no access to opportunities (zero spatial availability) and DAs with a small proportion of cyclists have relatively slow travel speeds compared to the car-using population. Though bike mode offers a relatively high opportunity range (cumulative opportunities), because of the low proportion of cyclist and their opportunity range compared to the _many_ other mode-users, they receive low spatial availability values.*

* Lines 301-303 fewer repetitions! Section 3.3 is difficult to follow

Thank you for pointing out this repletion. Thank you for your comments, we've largely revised this subsection in the results. The opening sentence to this subsection now more clearly reads:

> *"To draw insights on who may reside in DAs where populations are disadvantaged with low modal spatial availability and high low-income prevalence, a cross-tabulation is visualised in @fig-Fig6."*

* Add more description for the concept of "feminist accessibility analysis"

Thank you for your comment. Other reviewers also brought up this concern, so we've update the manuscript to more clearly define how we are using this concept in the manuscript. We've removed mentions of 'feminist' in the manuscript and now use the term 'gender-aware' when appropriate in the Introduction, and Discussion and Conclusions section in addition to changing the title of the manuscript to simply be "Exploring mobility of care with measures of accessibility". Hopefully these changes more accurately reflects what the study achieves.

* Error 393-395.

Thanks for catching this! We've removed this redundant heading.