Toward Equitable Service Provision: A Catchment Area Analysis of The Bike Share Toronto System

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I. Introduction

In the past 20-30 years, cities around the world have increasingly taken an interest in expanding and promoting active mobility means and networks, such as providing dedicated or protected bike lanes, bike share programs, and active mobility networks (City of Toronto, n.d.). Bike Share Toronto is Toronto's official docked bike-sharing system, sponsored by Tangerine Bank since 2011 (Bike Share Toronto, n.d.; El-Assi et al., 2017). Bike-sharing not only inherits the benefits of cycling but also provides additional incentives such as convenience and financial savings for its users (Fishman, 2016).

Despite these benefits, bike-sharing also faces challenges and barriers that may limit its accessibility and equity for diverse populations, especially due to its docked nature and the arising first and last-mile issues. With the golden exception of the Netherlands' extensive biking infrastructure, many cities' increasing interest in expanding active mobility networks has rarely extended beyond downtown districts (Annis, 2023; Fishman, 2016).

Bike-sharing has the potential to combat social exclusion by providing improved mobility options, but this requires careful operation and management. As such, ensuring equitable service provision is a critical consideration in the development and expansion of bike-sharing systems, to promote an inclusive and equitable society.

II. Objectives

This project aims to examine the Bike Share Toronto system from an equity perspective. We focus on the station catchment areas and the population groups that reside within them, and we address the following two research questions:

1. How equitable is the access to Bike Share Toronto for all Toronto residents, especially for population subgroups based on gender, income or ethnicity?
2. Which Bike Share Toronto service areas have higher or lower levels of equity, and where should the system expansion be prioritized to improve the service provision equity?

III. Data

Table 1: Data Sources

Name	Description	Format	Source (URL)	Accessed Time
Bikeshare Ridership	Toronto bike-share trip data for the whole year 2023	CSV	City of Toronto Open Data	2024-01-20
Bikeshare Stations	Toronto bike-share station information	JSON	Toronto Parking Authority through GBFS	2024-01-08
Road Network	OpenStreetMap road network data for Ontario, Canada	PBF	OpenStreetMap through Geofabrik	2024-01-08
2021 Census	2021 Canadian Census data	*sf* data.frame	Statistics Canada through *cancensus* package (von Bergmann et al., 2021)	2024-02-05

IV. Methods

We performed our analyses in *R* and ArcGIS Pro. Figure 1 below shows the workflow of our analyses.

i. Catchment Area Analysis

To measure the coverage area of each bike share station, we calculated the 15-minute walking distance network buffers around them, using the *r5r* package in *R* (Pereira et al., 2021). To avoid overlapping in catchment areas, we created Voronoi polygons (Okabe et al., 2009) based on Euclidean distance for each station and intersected them with the network buffers to get the non-overlapping coverage areas for each bike share station. Figure 1 above shows the non-overlapping catchment for each station.

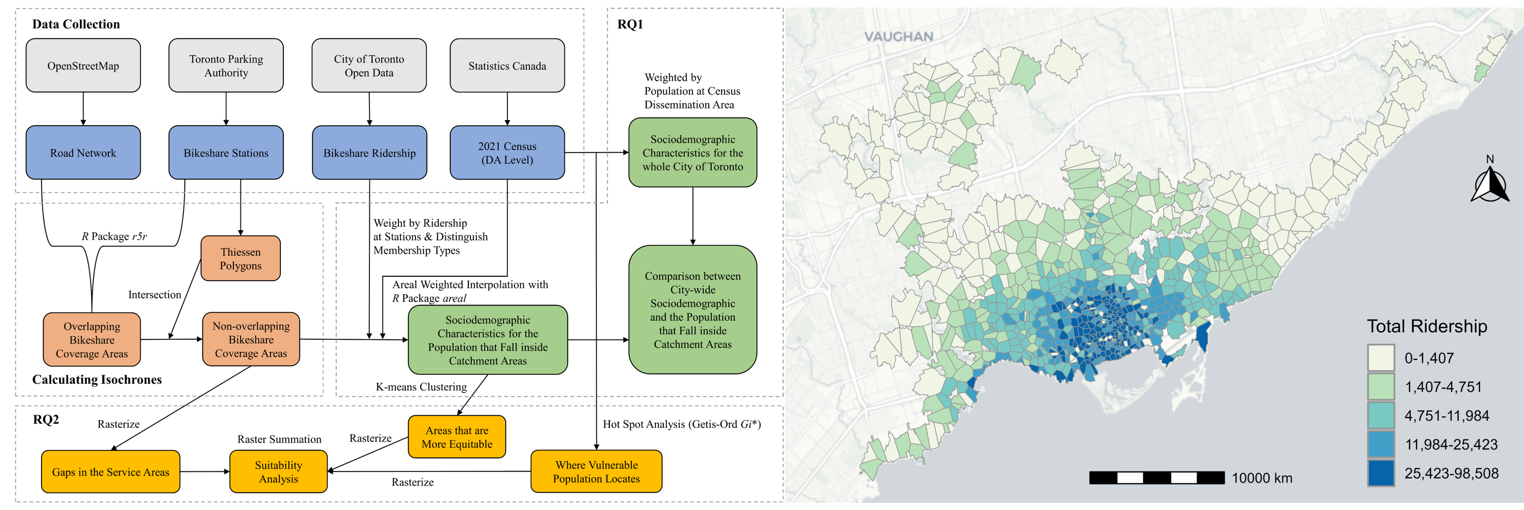

Figure 1: Workflow Diagram (Left) and Catchment Area Map (Right)

ii. Areal Weighted Interpolation

To construct metrics quantifying the service provision equity, we calculated eight socio-demographic variables: the percentages of Female, Indigenous people, White people, Chinese people, Black people, Latino people, people with household total income below $40,000, and people with household total income above $100,000 in 2020 for each census dissemination area in the City of Toronto. We used the *areal* package in *R* (Prener & Revord, 2019) to reshape the census data into the non-overlapping coverage areas, using the areal weighted interpolation method.

Areal weighted interpolation involves four steps:

1. Intersecting the non-overlapping coverage areas with the census dissemination areas.
2. Calculating an areal weight for each intersected feature, using $W_i = \frac{A_i}{\sum_i A_{ik}}$.
3. Estimating the share of the population value that occupies the intersected feature, using $E_i = V_j \times W_i$.
4. Summarizing the data based on the target identification number, using $G_k = \sum_i E_{ik}$.

Then, the Toronto Bike Share system-wide socio-demographics were calculated as a weighted average based on ridership at each station, $\overline{x} = \frac{\sum n \times x}{n}$.

iii. Cluster Analaysis and Hotspot Analysis

We applied the Multivariate Clustering Geoprocessing tool (K-means Clustering) in ArcGIS Pro to the eight socio-demographic variables of the bike share stations in order to group them into five clusters based on their attribute similarities. From these five clusters, we identified existing catchment areas that are relatively more equitable compared to others.

We used Hotspot Analysis or Getis-Ord Gi^* (Getis & Ord, 1992) to identify the census dissemination areas that have high or low values of the socio-demographic variables, compared to the surrounding areas. We employed a spatial weight matrix constructed using the 40-nearest neighbours method, along with the row standardized Bisquare Kernel Function, $w_{ij} = \left[1 - \left(\frac{d_{ij}}{\alpha_i}\right)^2\right]^2$ and $\sum_j w_{ij} = 1$.

iv. Suitability Analysis

We identified socio-demographic hotspots with a confidence level exceeding 90% and converted them into raster format, with cell values equal to the original socio-demographic variables. we created an approximate 1-kilometre buffer zone raster around the equitable catchment areas identified by the cluster analysis. We computed a weighted sum of these layers to ascertain the most suitable areas for the expansion of the Bike Share Toronto system. The weights for the socio-demographic hotspot layers were set as the inverse of their respective means, $w_i = \frac{1}{\mu_i}$. The buffer layer was assigned a weight of 1.2 to balance the importance of proximity to existing stations against the need to serve underserved populations.

V. Discussion and Conclusion

We scrutinized the Bike Share Toronto system through the lens of equity. Employing catchment area analysis, we discovered disparities in service provision: an oversupply to White, Chinese, and low-income populations contrasted with an undersupply to Black and female demographics. These findings indicate significant opportunities for enhancing the system's equitable distribution of services. Additionally, we performed a suitability analysis to pinpoint priority zones for potential network expansion, aiming to bolster equitable access across the city. The areas with the highest suitability scores include Scarborough's West Hill, North York, Yorkdale, and predominantly the Jane and Finch area.

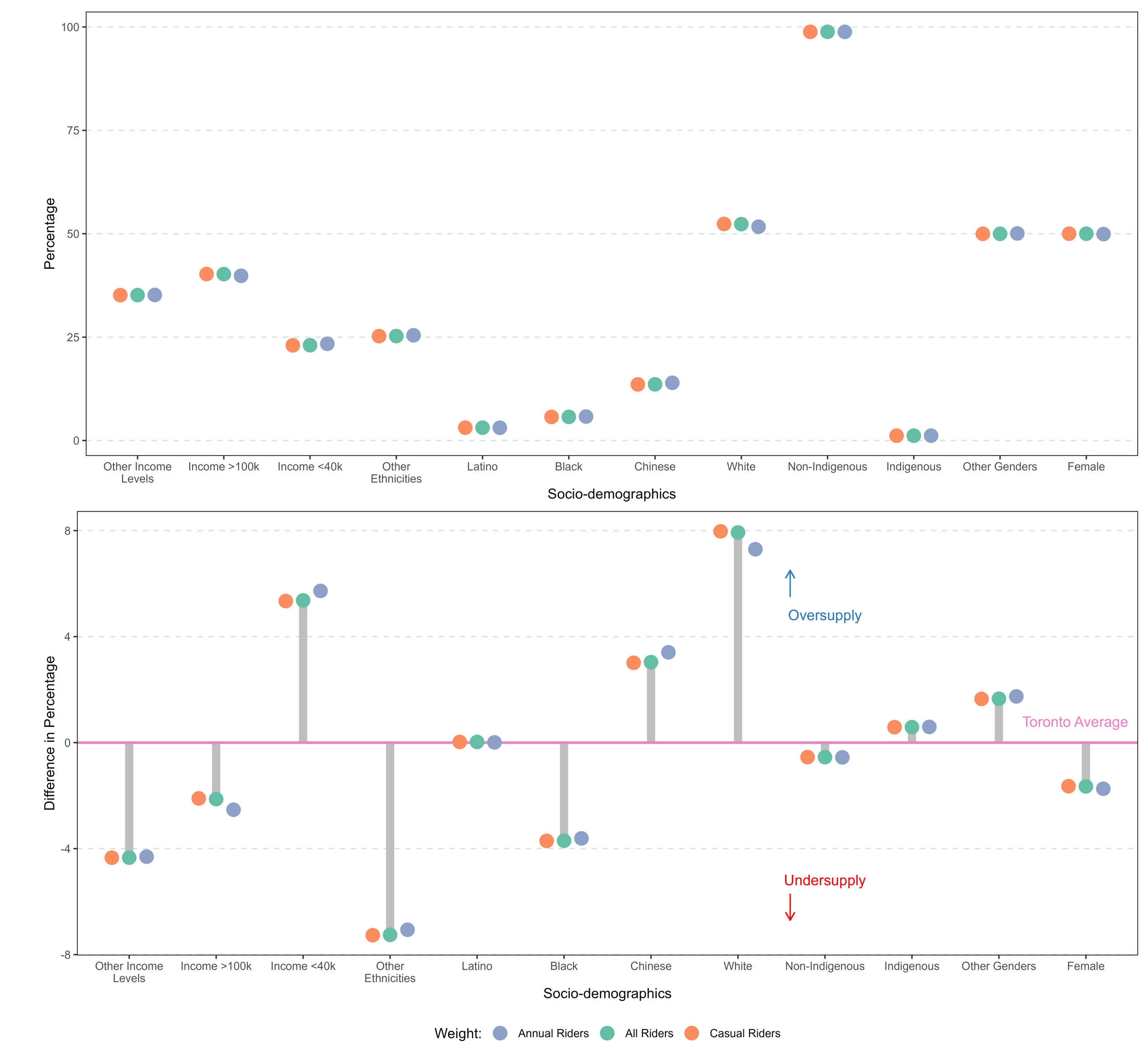

Figure 2: System Wide Equity Results

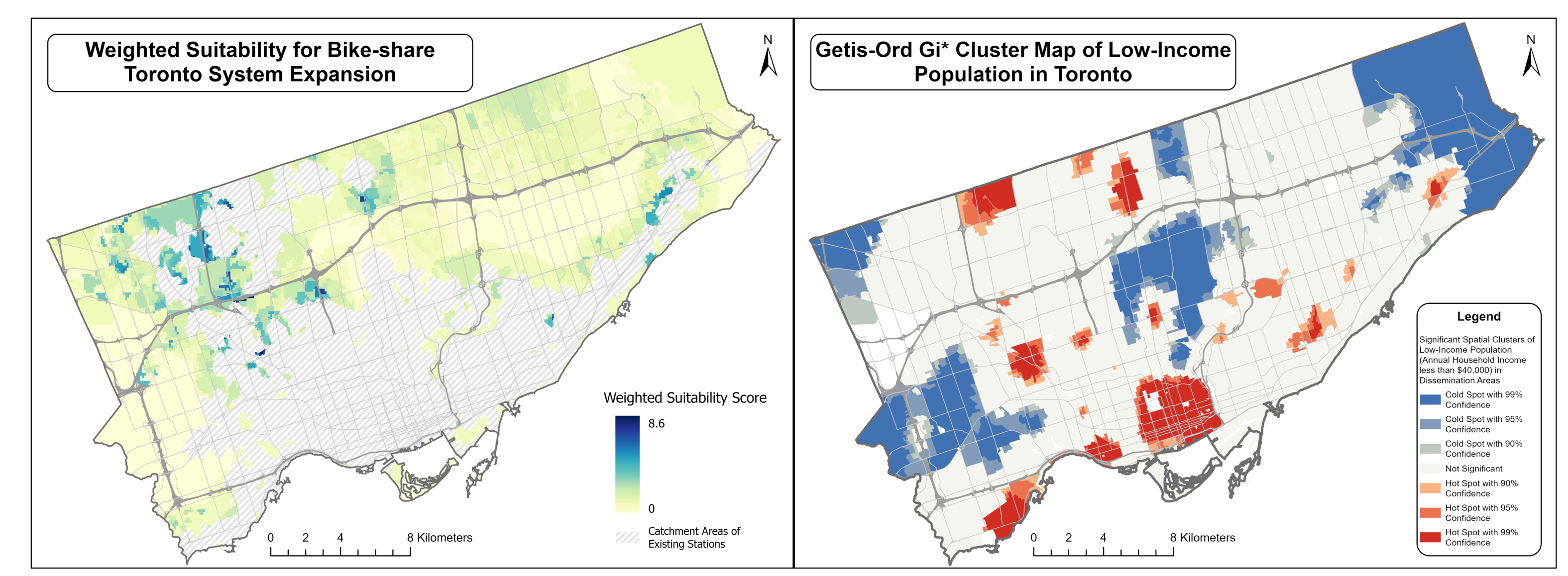

Figure 3: Priority Zone Map (Left) and Low-income Population Hotspot Map (Right)

Our analysis is subject to two primary constraints: 1) Due to the unavailability of historical data for bike share stations, our study is based on real-time station data. 2) The delineation of non-overlapping coverage areas was performed using Euclidean distance. While this method provides a general overview, it does not account for the actual travel distance along the road network, which could offer a more precise representation.

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