The future of urban cycling under a changing climate: the case study of Montreal

Xudong Wang*, Eduardo Adame Valenzuela, Chenglong You, Van-Thanh-Van Nguyen, Lijun Sun, Luis F. Miranda-Moreno

Department of Civil Engineering, McGill University, Montreal, Canada

Keywords: Climate Change, Urban Cycling, Ridership Prediction, Climate Models

1 INTRODUCTION

Since the mid-nineteenth century, the bicycle has emerged as one of the widely-used modes of transportation in urban environments. Its low acquisition and maintenance costs, combined with numerous health and mental benefits, make cycling an attractive option for individuals (Kaplan *et al.*, 2019). The advantages of cycling extend far beyond personal well-being. Increased cycling activity also contributes to substantial economic gains for cities and reduce air pollution in urban areas. Due to these wide-ranging benefits, many cities have begun actively promoting cycling through targeted campaigns, infrastructure investments, and policy initiatives. However, to further promote cycling, city authorities must consider long-term trends in bicycle ridership to design and build sustainable bicycle systems. Cycling is sensitive to weather conditions, such as temperature and precipitation (Miranda-Moreno & Nosal, 2011). In the context of global climate change, cities must better understand how local weather affects cycling demand and how these conditions can evolve over time. Although recent studies have examined the impact of climate change on cycling in various regions, there is a notable lack of research focused on Canada. Research indicates that both historical and projected warming in Canada is, on average, about twice the global rate (Bush & Lemmen, 2019). This significant increase in temperature highlights the urgent need to assess the effects of climate change on cycling infrastructure and usage across the country.

To achieve this goal, this study proposes a framework for predicting bicycle demand under various future climate scenarios. As illustrated in Figure 1, the framework consists of three components: (1) generating climate projections using statistical downscaling results from global climate models, such as CanESM2 (Arora *et al.*, 2011) and HadCM3 (Gordon *et al.*, 2000), in five different scenarios; (2) developing ridership-weather models based on historical data by XGBoost model (Chen & Guestrin, 2016); and (3) predicting future bicycle ridership by applying the trained models to alternative climate scenarios for 2050s. As a leader in the “cycling renaissance”, Montreal has constructed a network of 1,065 km of bike paths across the island by 2024 and continues to plan for further expansion (Ville de Montréal, 2024). Therefore, we use Montreal as a casestudy to evaluate the framework. The results of the climate models indicate that, by the 2050s, higher temperatures and reduced precipitation are expected. Consequently, the demand for cycling is projected to increase from 8.7% to 19.9%, suggesting that climate change could positively impact cycling in Montreal. This finding highlights the need for urban planning and investment in infrastructure to adapt to changing climate conditions, ensuring that cycling remains an attractive option for city residents.

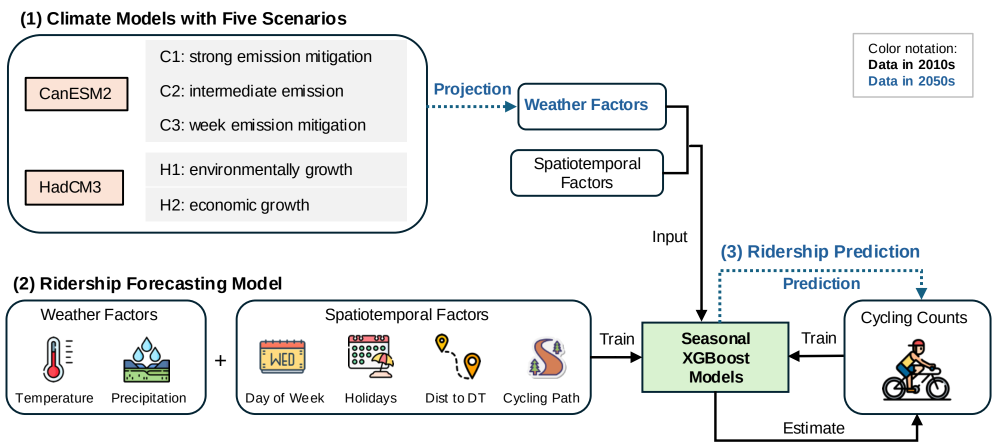

Figure 1 – *Flowchart of the proposed framework: (1) Generate localized climate projections, (2) Develop a ridership forecasting model, and (3) Predict cycling ridership under various climate scenarios*

2 METHODOLOGY

2.1 Climate Model

Bicycle counts show strong correlations with weather conditions, with temperature and precipitation being the most important factors.(Miranda-Moreno & Nosal, 2011). To obtain reliable cycling predictions under climate change, we use Global Climate Models (GCMs) to predict future climate by running various scenarios. However, GCMs typically operate at coarse spatial resolutions (larger than 200 km) that limits their direct application in climate change impact studies at a local scale. Hence, Statistical Downscaling Model (SDSM) have been used to link the large-scale atmospheric predictors given by GCMs to the observed weather series at a local site. Two prominent GCMs, the Canadian Earth System Model version 2 (CanESM2) (Arora *et al.*, 2011) and the Hadley Centre Coupled Model version 3 (HadCM3) (Gordon *et al.*, 2000) are used to project future weather conditions for 2050s. For CanESM2, we consider the climate change under three scenarios indicated by different radiative forcing levels, i.e., from strong emission strategy (C1) to intermediate strategy (C2) and to weak strategy (C3). Similarly for HadCM3, two scenarios are considered, one with a policy focused on environmentally sustainable growth (H1) and the other with a policy focused on economic growth (H2). For each scenario, we generate 100 weather sequences to capture the inherent randomness in the downscaling process.

2.2 Ridership Forecasting Model

To predict bicycle ridership in the future, we use XGBoost, a scalable and efficient machine learning algorithm (Chen & Guestrin, 2016). XGBoost exhibits superior performance in predictive tasks, and its effectiveness in the transportation field has been demonstrated in numerous studies. The dependent variable, bicycle ridership demand, are collected from nine sensor locations in Montreal. The weather variables, maximum temperature and daily precipitation, are incorporated as influential factors. In addition to weather factors, we also integrate other independent spatiotemporal variables that affect bicycle ridership, such as the day of the week (Monday, Tuesday, ..., Sunday), holiday/bridge days, the distance to downtown areas and cycling path density in our analysis.

We divide the data into a *training dataset* (2014-2017) and a *testing dataset* (2018). For each season, we construct a separate XGBoost model to account for the distinct travel patterns influenced by weather conditions. To identify the optimal hyperparameters for the XGBoost models, we first split the *training dataset* into a *training set* and a *validation set* in a 4:1 ratio. We then employ a RandomizedSearchCV with 5-fold cross-validation, which reduces the risk of overfitting while exploring various hyperparameter combinations systematically.

2.3 Ridership Prediction

The aim of this study is to evaluate how will climate change impact ridership in future. To achieve this goal, we use the predicted maximum temperature and daily precipitation from climate models and the trained XGBoost models to forecast ridership demand in the 2050s. For the year 2050, key weather variables are derived from five distinct scenarios. The remaining independent variables, such as those reflecting weekly and geographic patterns, are kept the same as in the 2018 dataset.

3 RESULTS

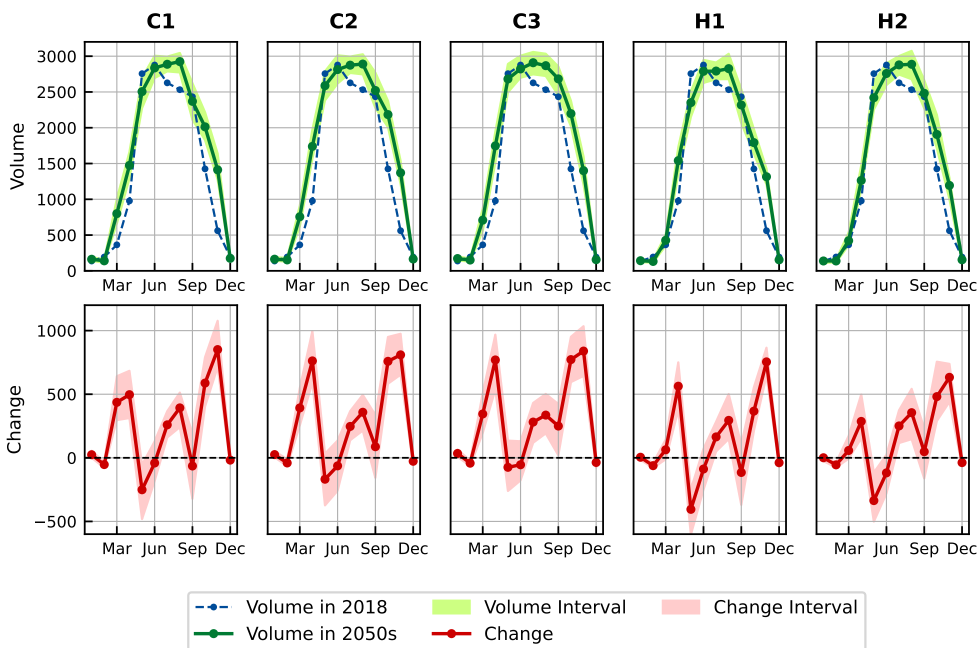

Figure 2 – *Monthly average ridership prediction in 2050s (top row) and corresponding ridership change (bottom row).*

Given that there are 100 sets of simulations for each climate scenario, we conduct 100 experiments for each season to obtain daily prediction results. Figure 2 illustrates the predicted ridership volume and the changes based on the weather projections from five climate scenarios. As seen in the figure, climate change is expected to increase ridership demand in most months, particularly in April, October, and November. Currently, temperatures in Montreal are typically low and precipitation is relatively high during these months, making them less conducive to cycling. However, with climate change, the temperature is higher and dryer; therefore, more people are likely to embrace cycling as a mode of transport. While ridership demand does increase in the summer, the rise is smaller compared to other seasons. A likely reason is that when temperatures exceed a certain threshold, the desire to cycle decreases (Chang *et al.*, 2024). There are notable differences in predictive performance between CanESM2 scenarios and HadCM3 scenarios due to their varying predictions of temperature and precipitation. For instance, CanESM2 scenarios indicate a significant increase in ridership for March, a trend that is not observed in HadCM3 scenarios. This discrepancy might due to the temperature projections, where CanESM2 scenarios forecast higher temperatures in March, which would likely encourage greater cycling demand.

To provide a holistic analysis of the effect of climate change on ridership demand in future, the Annual Average Daily Bike Traffic (AADBT) in 2050s is shown in Table 1. All the models show the increased volume change from 8.7% to 19.9%, indicating the climate change is benefit to cycling in Montreal. Specifically, ridership demand based on CanESM2 scenarios has larger demand than that on HadCM3 scenarios, because CanESM2 predicts higher temperature and less precipitation days. Among these five climate scenarios, C3 with weak mitigte policy attracts the most ridership demand. However, it has to be noted that we only consider temperature and precipitation caused by climate change in our study; other factors, like air quality is not included. Polluted air condition would decrease the demand.

	C1	C2	C3	H1	H2
AADBT in 2050s	1681 ± 18	1721 ± 18	1745 ± 17	1582 ± 15	1589 ± 15
Volume Change Rate (%)	15.5 ± 1.2	18.3 ± 1.2	19.9 ± 1.1	8.7 ± 1.0	9.2 ± 1.0

C1–C3: Emission scenarios from the CanESM2 model. Higher values indicate weaker mitigation efforts.
H1–H2: Emission scenarios from the HadCM3 model. H1: sustainability; H2: economic growth.

Table 1 – *Projected AADBT for 2050s under different climate scenarios, with standard deviations and volume change rates. AADBT in 2018 is 1455.*

4 DISCUSSION

This study investigates the potential effects of climate change on urban cycling in Montreal, Canada, under various future climate scenarios. The ridership prediction under different scenarios suggest that climate change may, in fact, benefit cycling in Montreal, particularly during the shoulder seasons when weather conditions are currently less favorable. This finding highlights the importance of adapting urban planning and infrastructure investment to changing climate conditions. The proposed framework can also be applied to other cities. As our main purpose is to examine how climate change would impact cycling demand; therefore, we did not account for potential increases in bicycle ridership driven by policy or economic factors. This can be a potential direction for future research. Due to page limitations, a more detailed analysis are available in our full paper.

References

Arora, Vivek K, Scinocca, JF, Boer, GJ, Christian, JR, Denman, KL, Flato, GM, Kharin, VV, Lee, WG, & Merryfield, WJ. 2011. Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases. *Geophysical Research Letters*, **38**(5).

Bush, E., & Lemmen, D.S. 2019. *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada.

Chang, Annie YJ, Wang, Xudong, Sharafi, Mojdeh, Miranda-Moreno, Luis, & Sun, Lijun. 2024. Headwind or tailwind? The evolution of bike-sharing and ride-hailing demand during the COVID-19 pandemic. *Journal of Transport Geography*, **118**, 103944.

Chen, Tianqi, & Guestrin, Carlos. 2016. Xgboost: A scalable tree boosting system. *Pages 785–794 of: Proceedings of the 22nd acm sigkdd international conference on knowledge discovery and data mining.*

Gordon, Chris, Cooper, Claire, Senior, Catherine A, Banks, Helene, Gregory, Jonathan M, Johns, Timothy C, Mitchell, John FB, & Wood, Richard A. 2000. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate dynamics*, **16**, 147–168.

Kaplan, Sigal, Wrzesinska, Dorota K, & Prato, Carlo Giacomo. 2019. Psychosocial benefits and positive mood related to habitual bicycle use. *Transportation Research Part F: Traffic Psychology and Behaviour*, **64**(Jul), 342–352.

Miranda-Moreno, Luis F, & Nosal, Thaddeus. 2011. Weather or Not to Cycle: Temporal Trends and Impact of Weather on Cycling in an Urban Environment. *Transportation Research Record*, **2247**(1), 42–52.

Ville de Montréal. 2024. *Cycling and bike paths*. https://montreal.ca/en/topics/cycling-and-bike-paths. Accessed: 15 October 2024.