

Analysis and Prediction of Shared Bicycle Usage at the University of Toronto St. George Campus*

Main Finding TBD

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Students and staff at the University of Toronto's St. George campus often face difficulties finding a bike-sharing parking spot when arriving at campus, and finding a bike when leaving, which highlights the need for effective prediction of future bike-sharing demand to support campus commuting infrastructure. This study uses Bayesian Poisson regression to predict the usage of bike-sharing stations at 27 locations on campus for specific years, months, and four-hour intervals of the day. The results indicate that, on September 26, 2025, from 4:00 to 8:00 AM, usage at 8 stations will increase by 3, 14 stations by 2, 3 stations by 1, 1 station remains unchanged, and 1 station will decrease by 1 compared to the same period in 2024.

1 Introduction

Bike-sharing services have undoubtedly improved commuting efficiency, especially for short trips within a campus. For example, a study on bike-sharing in Xiamen, China, highlighted how data-driven analyses can inform policymakers about system performance, thereby guiding investments and policy decisions to enhance urban mobility(Zhang, Gu, and Zhao 2024). However, in the Toronto region, despite a study by the University of Toronto's School of Cities showing that ridership increased from about 665,000 trips in 2015 to over 4.5 million in 2022(Liu and Allen 2023), there has been little research focused on small-scale areas, such as universities, within Toronto. Furthermore, a study from Hangzhou, China, confirmed the significant differences in traveling characteristics between cities and university campuses(Tang et al. 2020). Therefore, this paper takes the University of Toronto as a case study to analyze bike-sharing usage within the campus.

*Code and data are available at: <https://github.com/HaoweiFan0912/Bikeshare-Forecast.git>

The core of this study is to extract a sample of 27 bike-sharing stations within the University of Toronto campus from all bike-sharing usage data between January 1, 2017, and September 30, 2024. The total usage of bike-sharing at each station is calculated for each 4-hour interval. A Bayesian Poisson regression model is then employed to predict the usage based on the station, year, month, date, and the specific 4-hour interval of the day.

This study found that although the usage at all stations within the University of Toronto campus has increased rapidly each year, there are significant seasonal differences. During winter, usage at all stations, regardless of the year, remains close to zero. Additionally, from January to September each year, the usage shows an upward trend, which then gradually declines over the following months. There are also significant differences in usage across different times of the day. The period from 8 am to 8 pm accounts for an average of 79.8% of daily usage, while the period from midnight to 8 am accounts for only 6.8%. It is noteworthy that this project forecasts an average increase of 2 uses across 27 stations between 4:00 AM and 8:00 AM on September 26, 2025, compared to the same time period in 2024. Specifically, usage at 8 stations is expected to increase by 3, 14 stations by 2, and 3 stations by 1, while 1 station will remain unchanged and another will decrease by 1.

Compared to the general statistics on bike-sharing usage in the Greater Toronto Area, these findings offer more detailed recommendations specifically for transportation planning and policy adjustments within the University of Toronto campus. They also provide guidance on how to better allocate, deploy, or store shared bikes.

Structure: TBD

1.1 Estimand

This study aims to estimate the usage of a specific bike-sharing station within the University of Toronto campus during a particular 4-hour interval. By converting time into year, month, day, and the specific 4-hour interval of the day, it accounts for the overall trend, seasonal effects, and hourly variation in station usage. The core objective is to explore the temporal changes in the usage of 27 bike-sharing stations within the campus, thereby providing policymakers with recommendations for bike allocation to improve commuting efficiency on campus.

2 Data

2.1 Overview

The dataset used in this study comes from opendatatoronto (Gelfand 2022), uploaded by Toronto Parking Authority and collected by Bike Share Toronto. It records every bike-sharing usage in the Toronto area from 2015 to September 30, 2024, with a total of 28,017,329 records.

The variables included in the data differ across years, but they all contain the following variables: Trip ID, Trip Duration, Trip Start Station ID, Trip Start Time, Trip Start Station Location, Trip End Station ID, Trip End Time, Trip End Station Location, Bike ID, and User Type.

This study follows the workflow of Telling Stories with Data (Alexander 2023), using its initial folder structure and part of its code. Data downloading, cleaning, modeling, and visualization were carried out using R (R Core Team 2023). The following R libraries were also used alongside R:

tidyverse(Wickham et al. 2019): Used for data wrangling, cleaning, and analysis, integrating multiple data manipulation packages.

dplyr(Wickham et al. 2023): Used for data frame operations such as filtering, sorting, and aggregation.

arrow(Richardson et al. 2024): Used for reading and writing data in efficient formats like Parquet to speed up processing.

stringr(Wickham 2023): Used for handling and manipulating strings, allowing for text data cleaning and transformation.

readr(Wickham, Hester, and Bryan 2024): Used for fast reading of CSV and other text formats.

lubridate(Grolemund and Wickham 2011): Used for handling and converting date-time data, simplifying time-related data analysis.

brms(Bürkner 2017): Used for building and estimating Bayesian regression models for flexible data analysis.

rstanarm(Goodrich et al. 2022): Used for Bayesian regression modeling, helping to understand uncertainty better.

bayesplot(Gabry et al. 2019): Used for visualizing posterior distributions and diagnostic plots of Bayesian models.

ggplot2(Wickham 2016): Used for creating various types of plots, supporting exploratory data analysis and result presentation.

RColorBrewer(Neuwirth 2022): Used for generating color palettes to create visually distinct and appealing plots.

knitr(Xie 2014): Used for generating dynamic reports, integrating analysis results into documents.

kableExtra(Zhu 2024): Used for enhancing the presentation of tables, making tables in reports more visually appealing.

2.2 Measurement

To predict the relationship between bike-sharing usage and time within the University of Toronto’s St. George campus, this study requires a time series to describe the changes in usage at different stations over time. Therefore, the dataset published by opendatatoronto (Gelfand 2022), which records every instance of bike-sharing usage in the Toronto area since 2015, is ideal for this study. Additionally, this data is ideal because of its reliability—due to the commercial nature of bike-sharing, the specific time and location of each bike’s use and return are accurately recorded. However, the raw data cannot be used directly in this project; sophisticated data cleaning is required, with specific steps and reasons as follows:

First, data from 2015-2016 was excluded because the collection and recording methods for those years differ significantly from later years and do not include the time and station variables required for this study. Next, data for stations located within the University of Toronto’s St. George campus was extracted from all remaining samples, and the usage of each station was calculated for every four-hour interval. Finally, the data format was standardized for subsequent analysis. The cleaned data is in the format of Table 1.

Table 1: Samples of the dataset used for analysis

station_name	time	count
Willcocks St / St. George St	2024-09-29 12:00:00	1
Willcocks St / St. George St	2024-09-29 16:00:00	1
Willcocks St / St. George St	2024-09-30 04:00:00	1
Willcocks St / St. George St	2024-09-30 08:00:00	1
Willcocks St / St. George St	2024-09-30 12:00:00	7
Willcocks St / St. George St	2024-09-30 16:00:00	4

2.3 Variables

This study focuses on the following variables:

- **count:** The dependent variable of the study, a non-negative integer. It describes the total usage of bike-sharing at a particular station during a specific 4-hour interval.
- **time:** An independent variable representing the time interval. For example, “2024-09-29 12:00:00” represents the time interval from 12 pm to 4 pm on September 29, 2024, in a 24-hour format. The earliest time is “2017-01-01 00:00:00,” and the latest is “2024-09-30 24:00:00.”
- **station_name:** An independent variable representing the unique name of one of the 27 stations within the University of Toronto’s St. George campus.

Figure 1 shows the daily usage totals of 27 shared bicycle stations from January 1, 2017, to September 30, 2024. It can be observed that the overall usage exhibits a significant upward trend, particularly after 2021, where usage fluctuations increased noticeably. In 2024, several peaks in daily usage reached historical highs, indicating a substantial growth in user demand. Additionally, the data displays some seasonal variations, with noticeable declines during the winter months and increases during spring and summer.

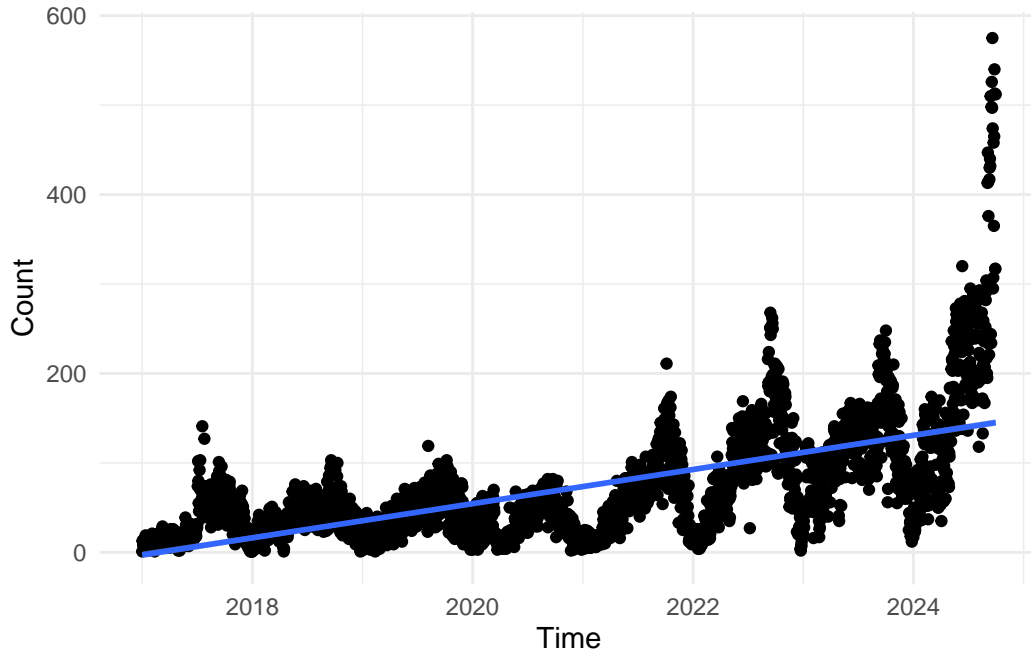


Figure 1: Daily usage from January 2017 to September 2024

shows the total usage and percentage of shared bicycles during different time intervals in a day from January 1, 2017, to September 30, 2024. It can be observed that the peak usage occurs between 12:00 to 16:00 (28.5%) and 16:00 to 20:00 (31.4%). The usage between 08:00 to 12:00 accounts for 19.9%, while the usage from 20:00 to 00:00 accounts for 13.4%. The time intervals with the lowest usage are 00:00 to 04:00 (3.6%) and 04:00 to 08:00 (3.2%).

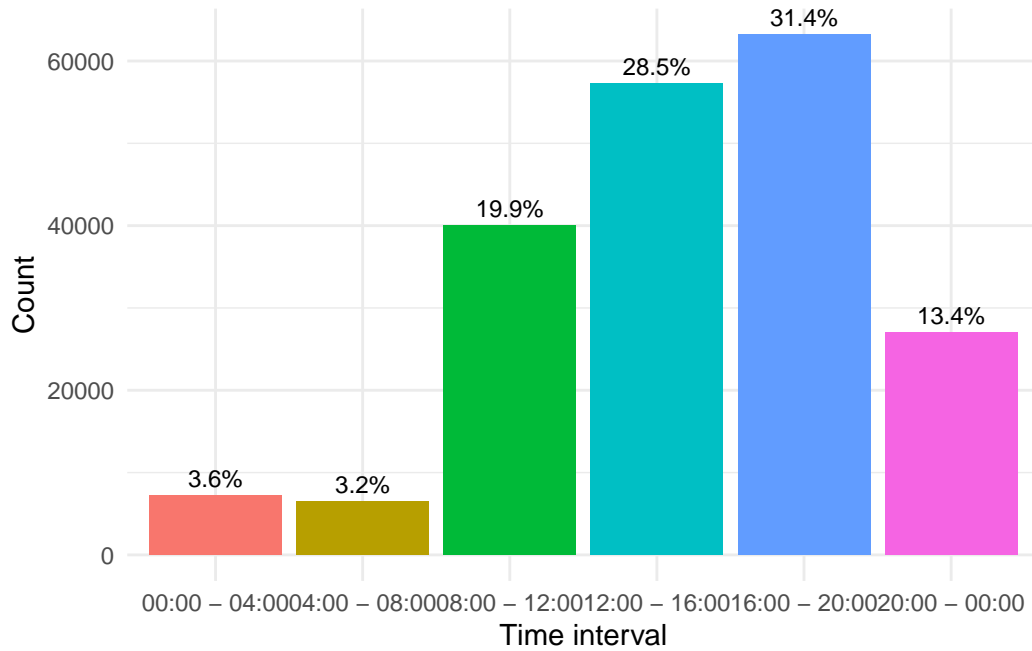


Figure 2: Total usage during different time periods from January 2017 to September 2024

Figure 3 shows the result of the average daily parking volume minus the departure volume at each station. It can be observed that most stations have balanced parking and departure volumes, but some stations show significant supply-demand differences. Specifically, stations such as Bay St / Charles St W – SMART and Bay St / Wellesley St W have noticeably higher departure volumes than parking, while College St / Huron St and College St / Henry St have higher parking volumes than departure, indicating an imbalance in supply and demand at these locations.



Figure 3: Difference of daily average of bicycle parking and departure volumes for each station

3 Model

The model used in this study is as follows:

$$\begin{aligned}
\text{count} &\sim \text{Poisson}(\lambda) \\
\log(\lambda) &= \beta_0 + \beta_1 \times \text{hour} + \beta_2 \times \text{day} + \beta_3 \times \text{month} + \beta_4 \times \text{year} \\
\beta_0 &\sim \mathcal{N}(0, 5) \\
\beta_j &\sim \mathcal{N}(0, 2) \quad \text{for } j = 1, 2, 3, 4
\end{aligned}$$

This study employs a Bayesian linear Poisson model to predict the variable **count**, which represents the expected number of bike-sharing usage events at a specific station on the St. George campus of the University of Toronto within a future 4-hour interval. The **count** is assumed to follow a $\text{Poisson}(\lambda)$ distribution, where $\log(\lambda)$ is the logarithmic transformation of the count. This transformation provides a simpler and more stable way to describe the relationship between the **count** and its influencing factors.

The predictors used in this model are as follows:

- year: The year of the time being predicted.
- month: The month of the time being predicted.
- day: The day of the month being predicted.
- hour: The time interval within the day being predicted. For example, a value of 12 represents the 4-hour interval from the 12th hour to the 16th hour in a 24-hour day.

The intercept β_0 represents the baseline level of the response variable **count** when all predictors (**year**, **month**, **day**, and **hour**) are zero. A relatively broad prior distribution, $\mathcal{N}(0, 5)$, is assigned to β_0 due to the lack of strong prior knowledge about the baseline demand. This allows the model to flexibly learn the actual baseline demand from the data. Additionally, given the potential for significant variability in baseline usage levels at different times, the broad prior ensures that the model can account for this uncertainty effectively.

For the coefficients $\beta_1, \beta_2, \beta_3, \beta_4$, which correspond to the predictors **hour**, **day**, **month**, and **year**, a narrower prior distribution, $\mathcal{N}(0, 2)$, is used. This reflects the assumption that the effects of these variables on **count** are likely to be moderate and within a reasonable range. The smaller standard deviation imposes stronger constraints on these effects, preventing them from causing unrealistic shifts in the predictions. At the same time, the prior remains flexible enough to allow the model to learn the actual effects of these time-related factors on demand patterns from the data.

This study employs the Poisson model, which assumes that the events under investigation are discrete and countable, occurring within a fixed time or spatial interval. Furthermore, it assumes that the occurrences of events are independent of each other, and the average rate of occurrence (λ) remains constant over the specified interval. Lastly, it is assumed that at most one event can occur within an extremely short time or spatial interval. These assumptions enable the Poisson distribution to effectively describe the probabilistic characteristics of the events.

3.1 Validation

Figure 4 is the residual plot. It demonstrates several strengths of the model. First, the residuals are primarily distributed around the zero line, indicating that the model does not exhibit significant systematic bias in its predictions. This suggests that the model is generally effective at capturing the central trends of the data. Second, the residual distribution shows a consistent linear pattern, reflecting the model's stability across different levels of fitted values. This consistency implies that the model performs reliably in its predictions for various ranges of the response variable. Third, the model successfully captures localized patterns in the data, as evidenced by the structured yet controlled behavior of the residuals.

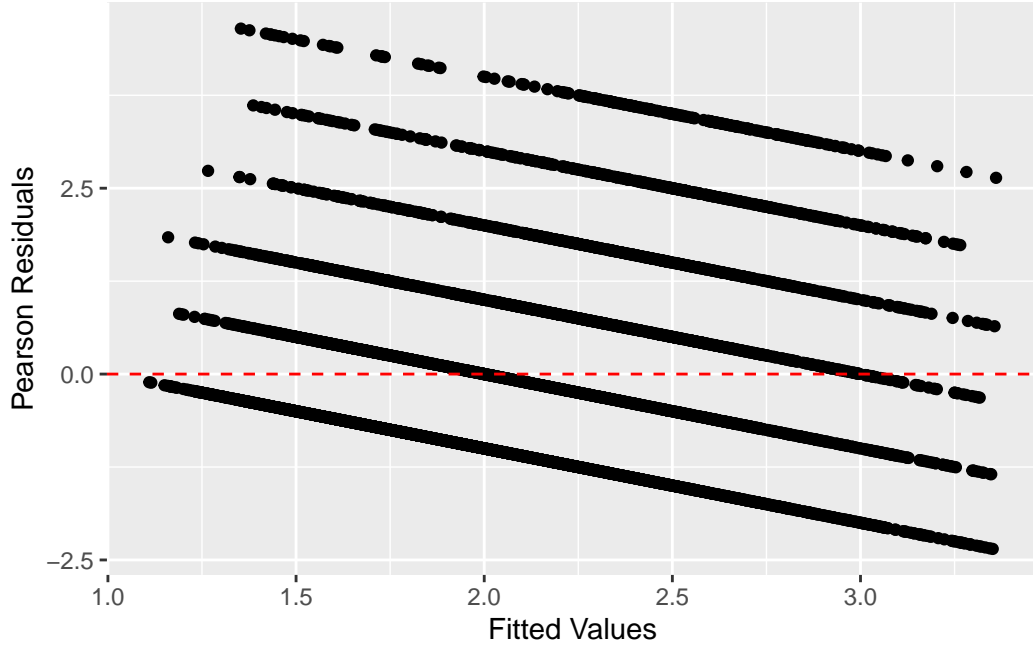


Figure 4: Pearson Residuals vs Fitted Values

Figure 5 is the posterior predictive check plot. The posterior predictive check plot highlights several strengths of the model. The predicted distribution (y_{rep}) closely aligns with the observed distribution (y), particularly at the primary density peak near 0 and the secondary peaks within the 2-5 range, indicating that the model effectively captures the overall data distribution. Additionally, the model successfully reflects the multimodal nature of the data, accurately identifying multiple peaks, which demonstrates its capability to handle complex data patterns. The tail behavior of the predicted distribution is also consistent with the observed distribution, showing that the model performs well in accounting for rare or extreme events. Furthermore, the uncertainty of the predicted distribution is appropriately moderate, neither too narrow to indicate overconfidence nor too wide to suggest excessive variability.

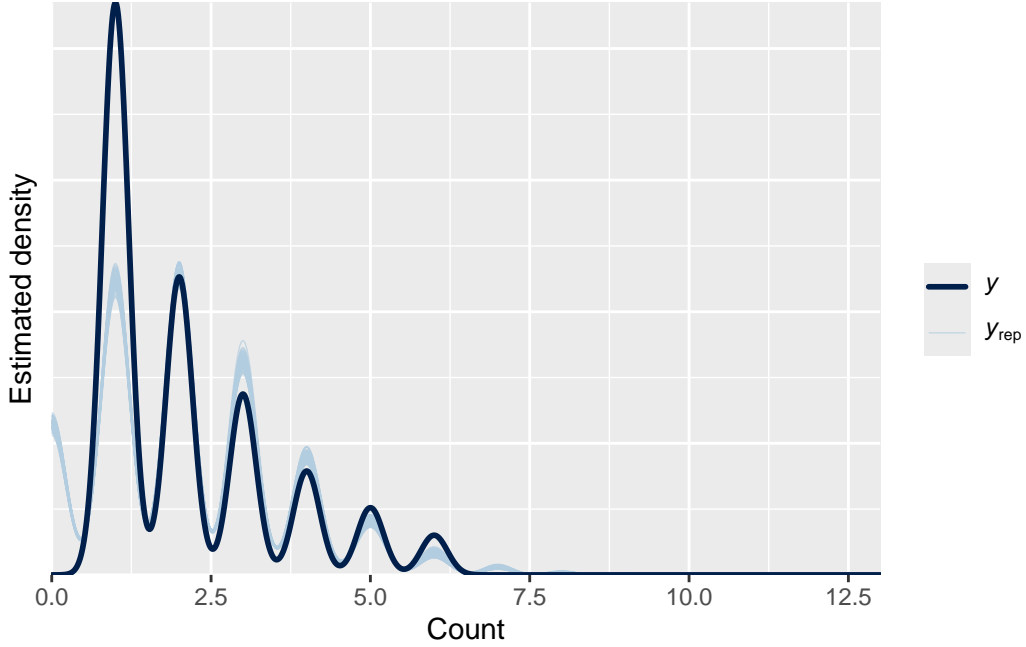


Figure 5: Posterior Predictive Checks

The credible intervals shown in Table 2 highlight several strengths of the model. Key variables such as hour, month, and year have narrow credible intervals that do not include zero, indicating their significant and consistent influence on the response variable. This demonstrates the model’s ability to effectively capture critical trends and relationships in the data, particularly those related to time and seasonal effects. Additionally, the relatively small width of these intervals reflects the stability and reliability of parameter estimates, suggesting that the model is well-calibrated and robust in its predictions. The intercept, while having a broader credible interval, provides a reasonable baseline estimate, reflecting the overall level of the response variable.

Table 2: Credible intervals

	2.5%	97.5%
(Intercept)	-194.34770387	-164.75862551
hour	0.01472614	0.02020263
day	-0.00300555	0.00050100
month	0.02355016	0.03368799
year	0.08172812	0.09633039

4 Results

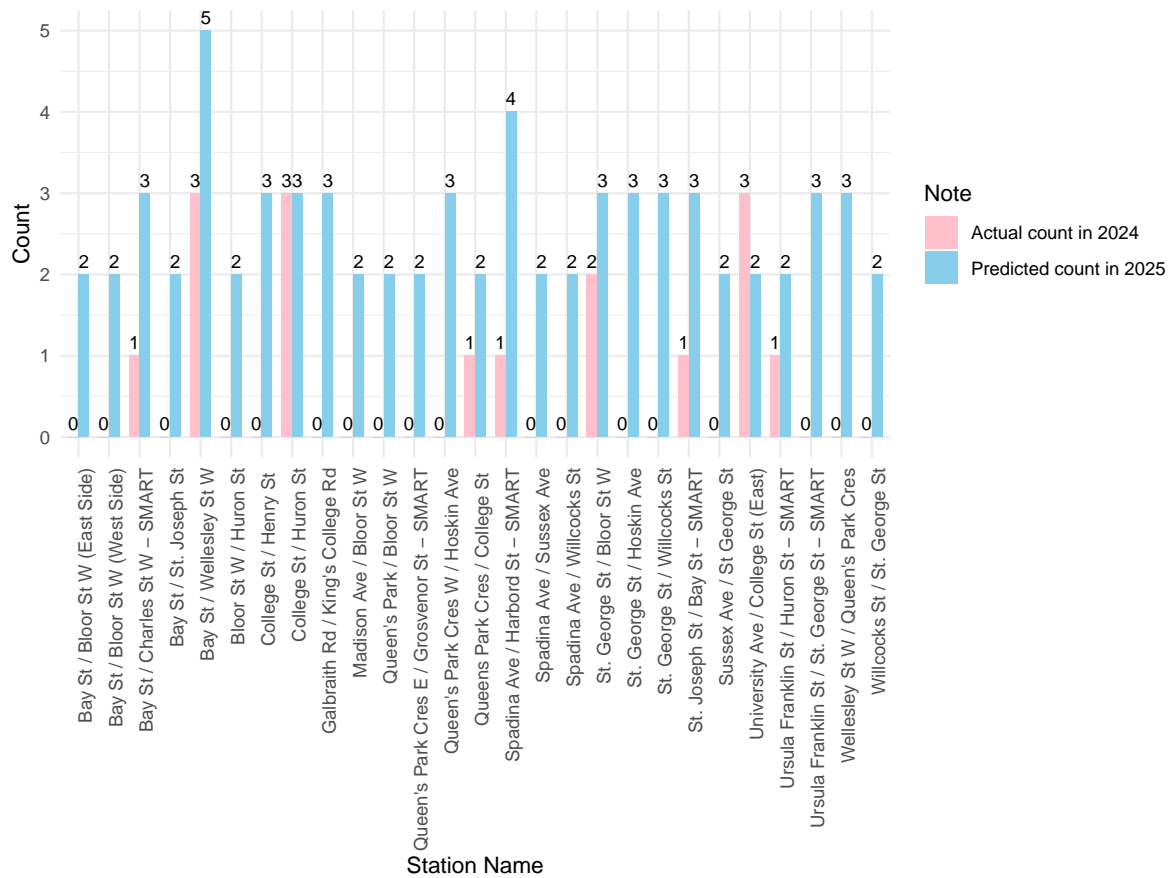


Figure 6: The actual count from 4:00 AM to 8:00 AM on September 26, 2024 vs the predicted count for the same time interval in 2025.

5 Discussion

Appendix

A Data collection methodology

A.1 Overview

Bike Share Toronto is the largest bike-sharing service provider in the Greater Toronto Area, committed to promoting gas-free transportation since its establishment. Starting with 79 stations in 2014, the system has expanded rapidly over the past decade. As of September 2024, the number of stations has grown to 855, capturing the entire bike-sharing market in Toronto (Liu and Allen 2023).

Bike Share Toronto uses its advanced bike-sharing system to automatically collect and manage ride data. Each bike and docking station is equipped with sensors and communication devices to record trip data in detail. This data is transmitted in real time to a central database via a wireless network, used for system monitoring, operational maintenance, and user behavior analysis. To support academic research and urban planning, Bike Share Toronto also anonymizes the data and makes it publicly available. This dataset includes all ride records since the system’s inception and is therefore considered a population rather than a sample.

With ongoing system and technological updates, the data collected and published each year varies. Data from 2014-2015 primarily captured hourly usage on weekdays and weekends. Starting in 2016, more detailed data was collected, including trip start and end stations, start and end times, trip duration, trip ID, and user type. From 2017 to 2023, the data was further refined with the addition of unique identifiers for each station (station ID). In 2024, information on bike models was added. The data release cycle also varied across different periods, with some data released quarterly and others monthly. Despite the consistency in the recorded content each year, variable names differ.

A.2 Evaluation

In evaluating the data collection methods, I focused on accuracy, completeness, consistency, and relevance to ensure the credibility and scientific quality of the research. Below is a detailed assessment of the Bike Share Toronto dataset:

Accuracy

Bike Share Toronto records ride data in real time through sensors and communication devices, an automated collection method that effectively reduces errors associated with manual recording. Additionally, data is directly stored in a central database and updated in real time, enhancing accuracy. However, sensor devices may be subject to hardware failures or communication interruptions, leading to minor data loss or errors. Although such occurrences are rare, they need to be addressed during data preprocessing.

Completeness

The dataset covers all ride records since 2014, with data variables expanding as the system and technology improved. This historical and comprehensive nature allows the data to reflect long-term trends in Toronto’s bike-sharing system. However, the limited variables in early data (e.g., only hourly usage for 2014-2015) require researchers to be mindful of inconsistencies across years, and early data may need supplementation or transformation to meet research needs.

Consistency

Although the Bike Share Toronto dataset has expanded annually with new variables, changes in variable names can pose challenges for data analysis. For instance, some variables have been named differently across different years, requiring standardization during data cleaning. Additionally, the variation in data release cycles (quarterly or monthly) could affect the continuity of time series analysis, necessitating data resampling or aggregation to ensure consistency.

Relevance

The detailed variables in the dataset (such as station ID, ride duration, and user type) provide opportunities for multidimensional analysis, enabling researchers to explore geographic distribution, temporal patterns, and user behavior. Since the dataset represents a population rather than a sample, researchers have greater flexibility in their study focus, ranging from micro-level user behavior to macro-level trend analysis. However, this comprehensiveness also increases the difficulty of data cleaning, such as dealing with redundant data, outliers, and the computational burden of large-scale data processing. Moreover, anonymization protects user privacy, it may limit certain studies focusing on micro-level user behavior.

B Idealized methodology

In an ideal research methodology, the design of data collection should emphasize comprehensiveness, systematic approach, and relevance, ensuring that the collected data can adequately reflect the multidimensional characteristics of the research subject. Specifically, in addition to core data from the bike-sharing system (such as ride duration, start and end stations, riding time, etc.), external environmental factors should also be considered, including weather conditions (temperature, precipitation, wind speed), holiday information (whether it is a public holiday, behavioral changes before and after holidays), traffic flow (interactions between shared bikes, motor vehicles, and public transportation), and socio-economic factors of the region (income levels, population density, and urbanization degree of different communities). These external variables provide richer contextual information for data analysis, thereby supporting more precise research conclusions.

Moreover, the comprehensiveness of data collection should not only reflect the diversity of variables but also consider continuity in temporal and spatial dimensions. Ideally, the data should cover the full-year operation of all stations in the bike-sharing system, with high-frequency recording (e.g., per minute or second) of trip dynamic data to avoid biases or misinterpretations due to data loss. A unified data format and standardized naming conventions should

be adopted to ensure compatibility between different time periods and various data sources, thereby achieving seamless data integration.

To address potential information gaps caused by facility malfunctions, several solutions can be implemented: firstly, multiple data collection devices should be integrated into the system to minimize the impact of a single device failure on overall data integrity. For instance, sensors on bicycles can serve as backups for station records, ensuring that even if one side fails, the other can still provide critical data. Secondly, the central database can be designed to automatically fill in missing data using mechanisms such as utilizing historical data, average values from neighboring stations, or similar time periods, thus reducing the impact of information gaps on the analysis results.

B.1 Ideal Dataset Framework

A well-designed ideal dataset framework should be comprehensive, flexible, and structured, enabling multidimensional analysis and dynamic scalability. Below is the proposed framework for a bike-sharing system dataset:

Temporal Dimensions

- Date: Year/Month/Day, supporting time-series analysis.
- Timestamp: Precise to the second, enabling high-precision analysis.
- Time Period: Categorized into morning peak, evening peak, weekdays/weekends, etc., for behavioral pattern analysis.

Spatial Dimensions

- Start Station ID: A unique identifier for the starting station.
- Start Station Name: Readable names for better understanding.
- End Station ID: A unique identifier for the destination station.
- End Station Name: Helps with geographic visualization.
- Latitude/Longitude: Precise coordinates for spatial analysis.

Trip Information

- Trip ID: A unique identifier for each trip.
- Trip Duration: Duration of the trip in seconds, indicating the trip length.
- Trip Distance: Distance traveled in meters, providing spatial context.
- Bike ID: A unique identifier for each bike.

User Information

- User Type: Differentiates between members and casual users.
- User Age: Estimated age range of the user, supporting demographic analysis.
- User Gender: Categorized as male, female, or other/unspecified.

Environmental Factors

- Weather Conditions: Includes temperature, humidity, precipitation, and wind speed.
- Air Quality Index: Provides environmental health metrics.
- Traffic Conditions: Includes road congestion index or traffic volume.

System Status

- Available Bikes at Start Station: Number of bikes available at the starting station at trip initiation.
- Available Docks at End Station: Number of free docks at the destination station at trip conclusion.
- Device Status: Indicates whether the equipment (e.g., sensors) is functioning properly.

Operations and Management

- Maintenance Records: Includes repair times and reasons for bikes and station facilities.
- Anomalies: Records equipment failures, data abnormalities, etc.

Data Quality

- Missing Data Flag: Indicates whether data is missing or contains substituted values.
- Data Source: Records the source or method of data collection (e.g., station sensors, user applications).

Table 3, Table 4, Table 5, Table 6, Table 7, Table 7 show a simulation of proposed ideal dataset.

Table 3: Simulated Ideal Dataset Part 1

Date	Timestamp	Time_Period	Start_Station_ID	Start_Station_Name
2024-10-30	2024-11-27 19:45:56	Weekend	188	Station 169
2024-11-25	2024-11-27 06:41:23	Weekday	137	Station 179
2024-10-31	2024-11-27 11:59:52	Evening Peak	154	Station 101

Table 3: Simulated Ideal Dataset Part 1

Date	Timestamp	Time_Period	Start_Station_ID	Start_Station_Name
2024-11-24	2024-11-27 08:40:55	Weekend	188	Station 104
2024-11-06	2024-11-27 19:09:16	Morning Peak	118	Station 169

Table 4: Simulated Ideal Dataset Part 2

End_Station_ID	End_Station_Name	Latitude	Longitude	Trip_ID
168	Station 178	43.66700	-79.31730	TRIP-3444
138	Station 142	43.60153	-79.35507	TRIP-9493
169	Station 119	43.60394	-79.36377	TRIP-1844
154	Station 125	43.69338	-79.34735	TRIP-5114
183	Station 153	43.61786	-79.33301	TRIP-8871

Table 5: Simulated Ideal Dataset Part 3

Trip_Duration_s	Trip_Distance_m	Bike_ID	User_Type	User_Age
941	5487	BIKE-7679	Member	60
1234	7811	BIKE-5803	Casual	19
2208	2733	BIKE-7290	Member	57
2946	7828	BIKE-2495	Member	29
2111	3037	BIKE-6856	Member	18

Table 6: Simulated Ideal Dataset Part 4

Weather_Conditions	Air_Quality_Index	Traffic_Conditions	Available_Bikes_at_Start_Station
Cloudy	73	High	18
Rainy	62	Low	20
Cloudy	14	High	18
Cloudy	14	High	9
Rainy	68	Moderate	4

Table 7: Simulated Ideal Dataset Part 5

Available_Docks_at_End_Station	Device_Status	Maintenance_Records
	19 Faulty	Minor Repair
	18 Operational	Minor Repair
	1 Faulty	None
	19 Faulty	None
	10 Operational	Minor Repair

Table 8: Simulated Ideal Dataset Part 6

User_Gender	Anomalies	Missing_Data_Flag	Data_Source
Male	Sensor Error	FALSE	Mobile App
Other	None	TRUE	Station Sensor
Male	Docking Failure	FALSE	System Log
Other	Sensor Error	TRUE	Mobile App
Male	None	TRUE	Station Sensor

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