

# Predicting Citi Bike Availability in NYC

DATA 698 Research Project

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## Abstract

The Citi Bike bikeshare in New York City provides a solution for the “first-” and “last-mile” connectivity in urban areas for individuals wanting to access the subway or bus line without walking. Citi Bike offers real-time availability of bicycles through the Citi Bike app and website, but the availability of a bicycle at the docking station upon arrival is not guaranteed at any time. The availability of bicycles is dependent on the riders themselves and the rebalancing strategies of Citi Bike operators. This project aims to accomplish three goals: 1) Determine the flow of bicycles throughout the Citi Bike system in New York City to identify neighborhoods with a surplus or shortage of Citi Bike availability. 2) Identify system rebalancing and its impact on the level of availability at a given station or cluster of stations. 3) Determine the best model to accurately predict the availability of bicycles based on day of the week, time of day, and location.

We examine the bike trip data from August through October 2022 and the bike availability counts by docking station for two weeks in November to identify the patterns of use and distinguishing factors to bike availability which reveal the challenges of operational rebalancing and frequency of zero-bike availability. In order to construct a real-world, user-friendly model, we apply two modeling techniques to the bike availability data. First, we cluster docking stations to establish quarter-mile based clusters informed by an acceptable walking distance. Second, we apply count data regression models to predict the bike availability count by cluster. The selected algorithm is a Poisson-based model with a comparable RMSE to the other attempted models and the lowest count of missed zero predictions. Based on the selected regression model of clustered docking stations, a working proof of concept was created to provide true bike availability predictions for location, day, and time.

**Key words:** *Bikeshare, Count Data, Poisson, Negative Binomial, Zero-Inflated*



Empty Citi Bike docking stations in Brooklyn, November 2022

## **Introduction**

### **The Author**

Philip Tanofsky is a software engineer lead and a Master's of Data Science student at City University of New York – School of Professional Studies. Philip lives with his roommate Speck, a terrier mix, in Brooklyn, New York. Philip would like to thank Dr. Paul Bailo and Alex Ng with support and guidance throughout the process and Evi Wiley for a lifetime of support.

### **The Problem**

New York City offers a multitude of transit options including the subway, buses, rideshare, taxis, and since 2013 a bikeshare option known as Citi Bike. The privately owned bikeshare system boasts a total of approximately 25,000 bicycles and over 1,700 stations in New York City, New York in parts of Manhattan, Brooklyn, Queens, and the Bronx along with stations in Jersey City and Hoboken in New Jersey. The bikeshare option provides a solution for the “first-” and “last-mile” connectivity in urban areas for individuals wanting to access the subway or bus line without walking. Citi Bike offers real-time availability of bicycles through the Citi Bike app and website, but the availability of a bicycle at the docking station upon arrival is not guaranteed at any time. The availability of bicycles is dependent on the riders themselves and the rebalancing strategies of Citi Bike operators.

The trip data is publicly provided by Citi Bike on a monthly basis. Docking station availability counts are available through a Citi Bike supported API. Both datasets of the bikeshare system can be used to examine ridership patterns and directions of flow based on time, date, and type of user. This project will attempt to construct a model of the Citi Bike bikeshare system to predict the number of available bikes within a quarter mile based on location and a future date and time by addressing the following goals.

1. Determine the flow of bicycles throughout the Citi Bike system in New York City to identify neighborhoods with a surplus or shortage of Citi Bike availability.
  2. Identify system rebalancing and its impact on the level of availability at a given station and cluster of stations.
  3. Determine the best model to accurately predict the availability of bicycles based on day of the week, time of day, and location.
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## **Literature Review**

For this project, we focus on a variety of algorithm model approaches used to predict bikesharing system station availability along with factors that determine the impacts to trip generation volumes. The literature review identifies the negative binomial based model as a common approach. The literature review also finds other model approaches to assess availability such as LDA, random forest, and neural networks. Finally, we focus the research on bikesharing system rebalancing techniques to better understand how the availability of bikes depends on the movement of bikes separate from user trips.

The literature review focuses primarily on docked, instead of dockless bike-sharing systems across the United States and international locations as the Citi Bike system of New York City is a dock-based system. The project research accounts for model approaches broader than availability prediction to yield a more comprehensive understanding of the strong spatial and temporal nature of the bike-trip data.

## Negative-Binomial Based Models

A majority of the literature on bikesharing availability focuses on negative binomial models due to overdispersion and high volume of zeros in the station-level data. The negative binomial models often rely on socio-demographic and weather factors in model construction.

Wang, Lindsey, Schoner, and Harrison (2016) apply log-linear and negative-binomial regression models to evaluate the factors of population size, trip attraction and transportation network as primary factors on average daily-station trips. Wang et al. (2016) confirm bikeshare locations near the Minneapolis central business district, college campuses, parks, and bodies of water have higher ridership. Wang et al. (2016) also identify a negative coefficient on the measure of station proximity indicating an over-saturation of bike stations can decrease ridership at the station level.

Hosseinzadeh, Karimpour, and Kluger (2021) assess two micromobility methods, e-scooters and bikesharing, to examine the spatial and temporal factors of ridership using models based on linear regression, negative-binomial regression, time series, and generalized additive before focusing on a combined negative-binomial generalized additive model to account for the overdispersion. Hosseinzadeh et al. (2021) identify the amount of rain, existence of thunderstorms, and temperature index as significant factors in ridership. Hosseinzadeh et al. (2021) also find the day of the week along with major holidays and special events impact micromobility use.

Ma, Ji, Jin, Wang, and He (2018) construct an approach based on activity spaces around metro stations which finds the activity space larger on weekdays compared to weekends. Ma et al. (2018) then apply two model types, ordinary least squares (OLS) regression and spatial error model (SEM) with a focus on several socio-demographic, travel-related, and built-environment factors that uncover spatial autocorrelation in the trip data. Ma et al. (2018) observe the SEM outperforms the OLS regression based on model fit with results showing proportion of local residents increases activity size on the weekends while high job-density significantly decreases the activity size on the weekdays leading to a severe imbalance of bike availability on weekdays.

Wang and Chen (2020) explore built-environment, bicycle-infrastructure, and transit-related factors to predict bikeshare station capacity using several models — negative binomial, zero-inflated negative-binomial (ZINB), negative binomial-structural equation model (SEM), and finally a combined ZINB-SEM. The integrated approach of ZINB and SEM addresses the impact of excess zeros found at the station level. Wang and Chen (2020) posit the number of docking stations plays a more important role in attracting ridership over factors such as sidewalk length, population density, job density, and areas of green space. Wang and Chen (2020) determine the number of nearby stations, the number of bicycle racks, and bike route length have a greater impact on trip generation at the station level and also observe food services demonstrate an important role in bikeshare use.

Noland, Smart, and Guo (2016) develop trip-generation models that account for proximity of subway stations as a prominent factor. Noland et al. (2016) separate the models by key factors such as day of the week and type of user (subscriber or casual) while controlling for spatial autocorrelation. The results identify clear seasonal and weekly variations in the bikeshare usage. Noland et al. (2016) follow an intuitive approach of dissecting the data to generate several models based on commonalities instead of a single model in order to improve availability forecasting. The results recognize weather and user-base growth as impediments to accurate forecasting.

## Alternate Model Approaches

To broaden the understanding of model approaches to bikesharing availability, the literature review expands to research attempting alternate model approaches in evaluating the bikesharing system through Latent Dirichlet allocation (LDA) topic modeling, random forest classification, and multi-layer neural network prediction model.

Li, Huang, and Axhausen (2020) take a different approach for predicting bicycle accessibility by using Dirichlet multinomial regression (DMR) topic modeling based on LDA topic modeling to determine the

destination activities for a dockless system while also utilizing a distance decay model. The DMR model predicts the purpose of bike trips based on the points of interest near trip destinations along with arrival times. While the system under consideration is dockless, Li et al. (2020) identify longer trip distances for leisure activities over targeted destinations such as work and school. The model confirms bike accessibility decreases further from the city center and points of interest.

Zhou, Wang, and Li (2019) apply a classification approach to predict the likelihood of an individual selecting bikesharing or a taxi through spatiotemporal distributions of trip patterns. Zhou et al. (2019) settle on a random forest model based on features including travel distance, time of day, travel directions, weather and land use to predict the mode of transportation. After attempting models based on simple logistic regression and multi-layer neural network, the random forest model proved most valuable based on accuracy and better computational cost.

Lin, He, and Peeta (2018) predict hourly usage at a station level using a graph convolutional neural network with data-driven graph filter (GCNN-DDGF) for adjacency matrices based on spatial distance, demand, average trip duration, and demand correlation. Lin et al. (2018) find the neural network uncovers hidden heterogeneous pairwise correlations between stations labeled as communities to predict the station-level demand without reliance on the weather, socio-demographic, and built environment factors common among most bikesharing system research.

Hyland, Hong, Pinto and Chen (2018) use a hybrid approach combining clustering and regression to model the bikeshare usage. The clustering approach separated the bikeshare stations into clusters based on types of trips (work or leisure) along with proximity to other bikeshare stations. Hyland et al. (2018) then apply regression algorithms to forecast interactions between the station-clusters via a clustering approach. Hyland et al. (2018) also include other societal and economic data such as labor-force participation, mean income, and population density in the regression models of usage. The clustering of stations by usage type and location provides a blueprint for viewing availability not as a station-by-station model but instead based on clusters of stations formed by physical proximity and usage type.

## System Rebalancing

Finally, we wanted to better understand the system rebalancing efforts that directly impact the availability of bikes. Many of the bikesharing systems utilize a form of rebalancing to ensure a greater availability of bikes during high-demand times and high-demand locations. The rebalancing by definition disrupts the natural pattern of user-generated trips.

Qian, Jaller, and Circella (2022) attempt to find an equitable distribution of bikeshare stations through an optimization model defined as a genetic algorithm inspired by natural selection. Qian et al. (2022) find that maximizing revenue through rebalancing results in a smaller network of stations and does not promote accessibility of bikeshare stations to disadvantaged communities. Qian et al. (2022) use the 2016 expansion of Divvy stations in Chicago to evaluate their forecast of additional stations based on two goals: maximizing revenue and improving bikeshare accessibility to disadvantaged communities. Qian et al. (2022) conclude the two goals do not work in concert and thus provide a policy suggestion in which local governments can offer incentives to private companies to improve equitable distribution.

Médard de Chardon, Caruso, and Thomas (2016) focus on existing rebalancing operations through spatial and temporal exploration of the bikeshare trip data across many cities. Medard de Chardon et al. (2016) find rebalancing efforts directly impact the availability of bikes at transit hubs. Medard de Chardon et al. (2016) conclude the aggregation of spatio-temporal trip flow cannot be strictly understood as the spatial demand, and natural flow of trips are influenced by system rebalancing. Chardon et al. (2016) also identify induced demand based on rebalancing. Rebalancing strategies are deemed necessary to maintain a high quality of customer service that possibly run counter to the operations defined service-level agreements, profit increases, or trip maximizations.

The literature review provides a broad perspective of model algorithms for predicting bikesharing system availability at the station level from negative binomial to neural networks. The research also identifies

common factors, including day of the week, weather, and socio-demographic information, that directly impact bikesharing use. Finally, the review of system rebalancing provides additional insight into the greater movement of bikes throughout the system which directly impacts availability and trip generation volumes.

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## Methodology

As stated previously, our research attempts to answer the following goals:

1. Determine the flow of bicycles throughout the Citi Bike system in New York City to identify neighborhoods with a surplus or shortage of Citi Bike availability.
2. Identify system rebalancing and its impact on the level of availability at a given station and cluster of stations.
3. Determine the best model to accurately predict the availability of bicycles based on day of the week, time of day, and location.

Our methodology for addressing these aims follows the steps listed below: Data Collection & Preprocessing, Data Exploration & Analysis, Hierarchical Clustering, and Count Data Regression Modeling. The nature of each is described below:

**Data Collection & Preprocessing:** The data collection followed two separate techniques. First, the trip data for three months was downloaded and used to create a timetable for the surplus or shortage of every docking station in New York City. Second, the bike availability for every docking station was retrieved from an API based on a running script to construct a timetable of bikes available every 15 minutes across a two-week period.

**Data Exploration & Analysis:** The bike trip data was evaluated to understand the pattern of Citi Bike usage across New York City and comprehend the patterns across days of the week and dependency on time of day. The analysis of bike trips uncovered the system rebalancing but could not confirm the rebalancing patterns at the docking-station level thus motivating the reliance on the two weeks of station availability data to predict available bike counts. The exploration also identified the overwhelming number of docking stations across the NYC system thus placing constraints on the proposed prediction model.

**Hierarchical Clustering:** To fulfill the goal of a prediction model based on location, clustering was performed on the docking stations in order to decrease the size of the model and also provide a better real-world approach to end-user bike availability.

**Count Data Regression Modeling:** For identification and evaluation of count data regression models, we constructed several predictive models for count data to identify the most accurate model. The best model for bike availability prediction was selected based on RMSE, MAE, MASE, and zero count error rate. The count data regression models were evaluated based on a train-test data split approach.

Based on the selected count data regression model of clustered docking stations, a working proof of concept was created to provide bike availability predictions for location, day, and time.

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## Data Collection & Preprocessing

### Data Collection

This project relies on two primary data sources from Citi Bike. The first dataset, the complete set of bike trips for the three months spanning August–October 2022 is used to identify the patterns of bike use across

New York City. The second dataset is an aggregation of each docking station status every 15 minutes for the two-week period of Monday, Oct. 31, 2022 through Sunday, Nov. 13, 2022. The station status API provided the real-time bike availability count of every docking station in the Citi Bike system. This two-week dataset provides an accurate depiction of the available bikes, intentionally accounting for operational rebalancing.

Citi Bike provides individual bike trip data on a monthly basis available at <https://ride.citibikenyc.com/system-data>. This project uses three months of NYC-scoped bike trip data from August through October 2022. A note on the system data webpage indicates trips taken by staff to service or inspect the system have been removed from the dataset. Also, any trips below 60 seconds have also been omitted. With this pruning by the system operators, the remaining trips are considered to be valid bike trips. The dataset contains 13 variables for each bike trip originating at a NYC-based docking station.

- **ride.id:** Unique identifier of the bike trip
- **rideable.type:** Factor variable – classic, electric, and docked
- **started.at:** Timestamp of trip departure
- **ended.at:** Timestamp of trip arrival
- **start.station.name:** Name of departure docking station
- **start.station.id:** Unique identifier of departure docking station
- **end.station.name:** Name of arrival docking station
- **end.station.id:** Unique identifier of arrival docking station
- **start.lat:** Latitude of departure location
- **start.lng:** Longitude of departure location
- **end.lat:** Latitude of arrival location
- **end.lng:** Longitude of arrival location
- **member.casual:** Factor variable for user type – member or casual

Based on the **started.at** and **ended.at** variables, four variables are derived for each bike trip.

- **day:** Day of the month
- **start.hour:** Hour of the trip departure
- **weekday:** Day of the week for the trip
- **trip.duration:** Duration of bike trip in minutes.

The station status API (<https://github.com/MobilityData/gbfs/blob/master/gbfs.md>) response contains the bike availability counts for every docking station in the Citi Bike system. The API contains the following pertinent variables for this research project. The total number of available bikes is the sum of **num.ebikes.available** and **num.bikes.available**.

- **num.ebikes.available:** Number of electric bikes available
- **station.id:** Unique station identifier
- **station.status:** Status of station as "active" or "out of service"
- **num.bikes.available:** Number of classic bikes available

The station information API, also available from Citi Bike, provided the following pertinent variables for each docking station in the system.

- **short.name:** Unique station name (numerical)
- **lat:** Latitude of the docking station
- **lon:** Longitude of the docking station
- **station.id:** Unique station identifier
- **capacity:** Capacity of the docking station

The NYC Open Data (free public data published by New York City agencies and partners) provides a GeoJSON file for the polygons defining each neighborhood in NYC according to the 2010 Neighborhood Tabulation Areas (NTAs). Each NTA is associated with one of the five NYC boroughs. This data was determined the borough and neighborhood for each docking station.

The elevation of each Citi Bike docking station is determined using the R library `elevatr` based on the latitude and longitude of each station. The elevation is defined in meters above sea level.

- **elevation:** Units above sea level
- **elev.units:** Unit of measurement for elevation – meters

## Challenges

We faced three primary challenges during this research project. First, the large volume of data proved overwhelming for the personal computing processors used. Given the count of over 10 million trips and over 1,700 docking stations in NYC, the large data provided a base for several interesting data visualizations but pushed the available computing processors to their limits. The computing power limits ultimately informed the decision to focus the prediction model on the borough of Brooklyn instead of the entirety of NYC.

The second challenge to overcome was the inability to account for system rebalancing performed by the Citi Bike staff. Rebalancing is the movement of bikes by the system operators. These bike movements are not accounted for in the publicly available three months of bike trip data. For each of the three months, the Citi Bike staff rebalanced over 70,000 bikes which equates to an average of over 2,000 rebalanced bikes per day. This inability to comprehensively identify rebalanced bikes was the motivation to retrieve accurate availability information through the API.

The final challenge addressed was self-induced and the primary factor for the few independent variables used as input into the prediction model. We wanted to build a user-friendly model to predict bike availability. We envisioned a website or app requiring just a few inputs from a user to then provide the model prediction. This constraint forced us to limit the model inputs to information available to a given user.

## Data Preprocessing

Upon initial inspection of the 10,210,102 bike trips in August through October 2022, a total of 24,887 entries did not contain a value for `end.station.id` and `end.station.name`. These 24,887 without a defined destination docking station will be defined as “Abandoned,” meaning the user did not properly dock the bike. For this purpose, the `end.lat` and `end.lng` will be removed as the abandoned bikes temporarily remove a bike from the bikeshare system. Another rider cannot rent an abandoned bike until the bike is properly docked. As a note, Citi Bike does charge a fine for bikes not properly returned to a docking station.

Evaluation of the `end.station.id` for the NYC-based bike trips includes docking stations located in New Jersey. The Citi Bike bikeshare system does include docking stations in Jersey City and Hoboken. A number of bike trips end in New Jersey which does remove the bike from the NYC-based docking stations of which this research is focused. The trips remain in the dataset as they directly impact the count of available bikes in New York City.

**Surplus Calculation** The individual bike trip information was sorted by timestamp and grouped by docking station for each 15-minute interval across the three months to count the number of bikes departing and the number bikes arriving per interval. By subtracting the number of departures from the number of arrivals for each station for each interval, we are able to determine the increase or decrease of bikes at the docking station. This total is defined as the variable `surplus`. A summation of the `surplus` for each docking station is calculated over the course of the three months to determine which docking stations are more likely departure stations or arrival stations.

**Availability** To prepare the bike availability counts by docking station, we constructed a data table of the 1,344 API request made every 15 minutes from a chron script over the course of the two weeks. The sum of the available classic bikes with electric bikes defines the bike availability count for each docking station at the time of the API request. The data table was joined by `station.id` with the station information dataset to align the docking station capacity with the availability numbers and also identify the borough and neighborhood for each station. The API reported several docking stations with more available bikes than capacity of the docking station. In these instances, the availability was decreased to match the total capacity of the docking station.

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## Data Exploration & Analysis

We perform exploratory data analysis on the Citi Bike trips for August through October 2022 to evaluate the patterns of bike use and identify docking stations with a surplus or a shortage. First, the count of bike trips are assessed to find the high volume days of the week and time of day. Next, the duration of bike trips are evaluated to assess when bikes are individually likely to be unavailable longer. Finally, the surplus of bikes by docking station and borough are analyzed to determine which areas of New York City are more prone to having lower bike availability.

For understanding the ridership patterns of the Citi Bike system, the following statistics outline the breadth of the bike trip information assessed.

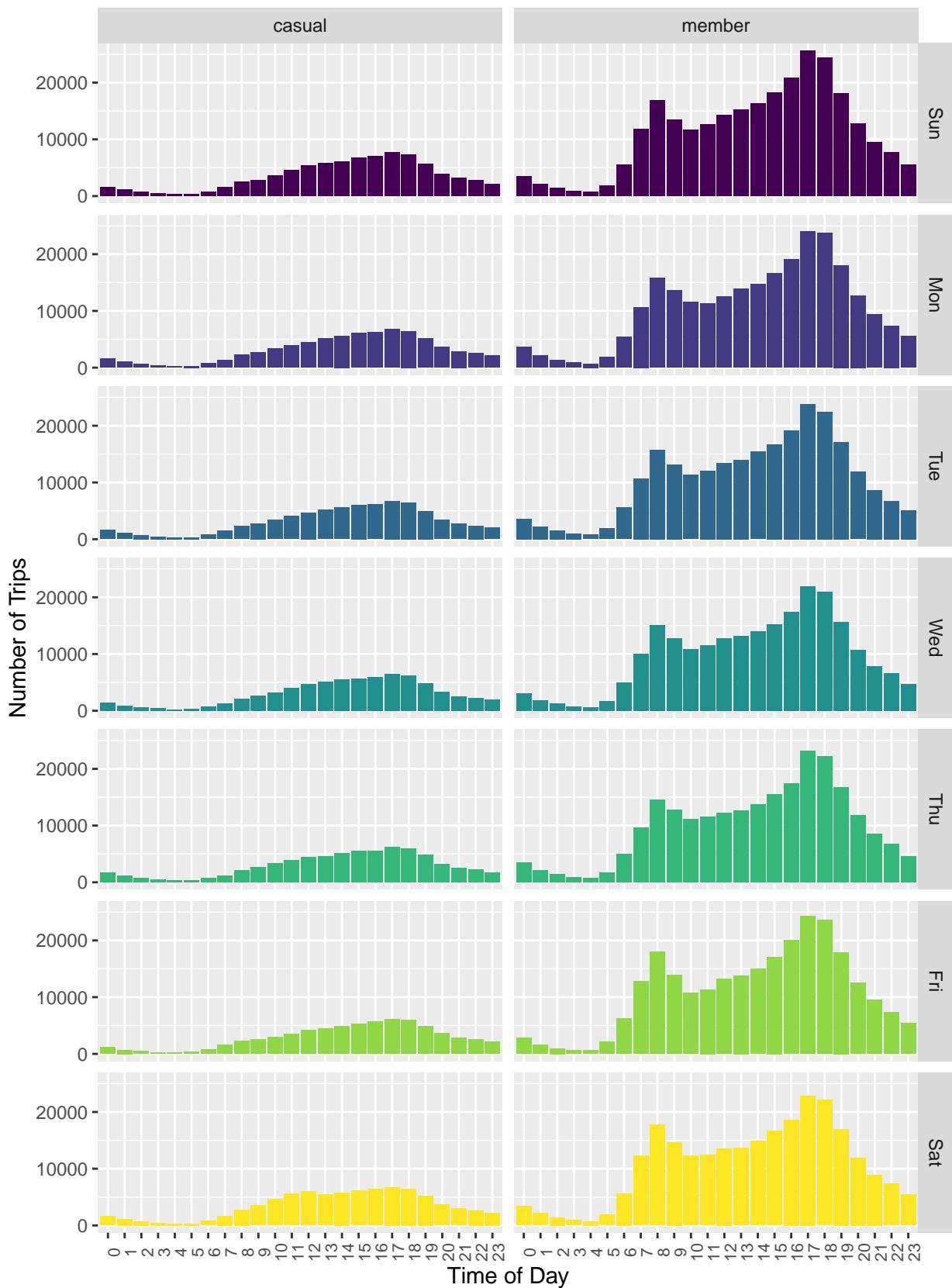
- **Timeframe:** August - October of 2022 (92 days)
- **Location:** New York City departing trips
- **Total trips:** 10,210,102
- **Total docking stations:** 1,716
- **Abandoned trips:** 24,887

### Count of Bike Trips

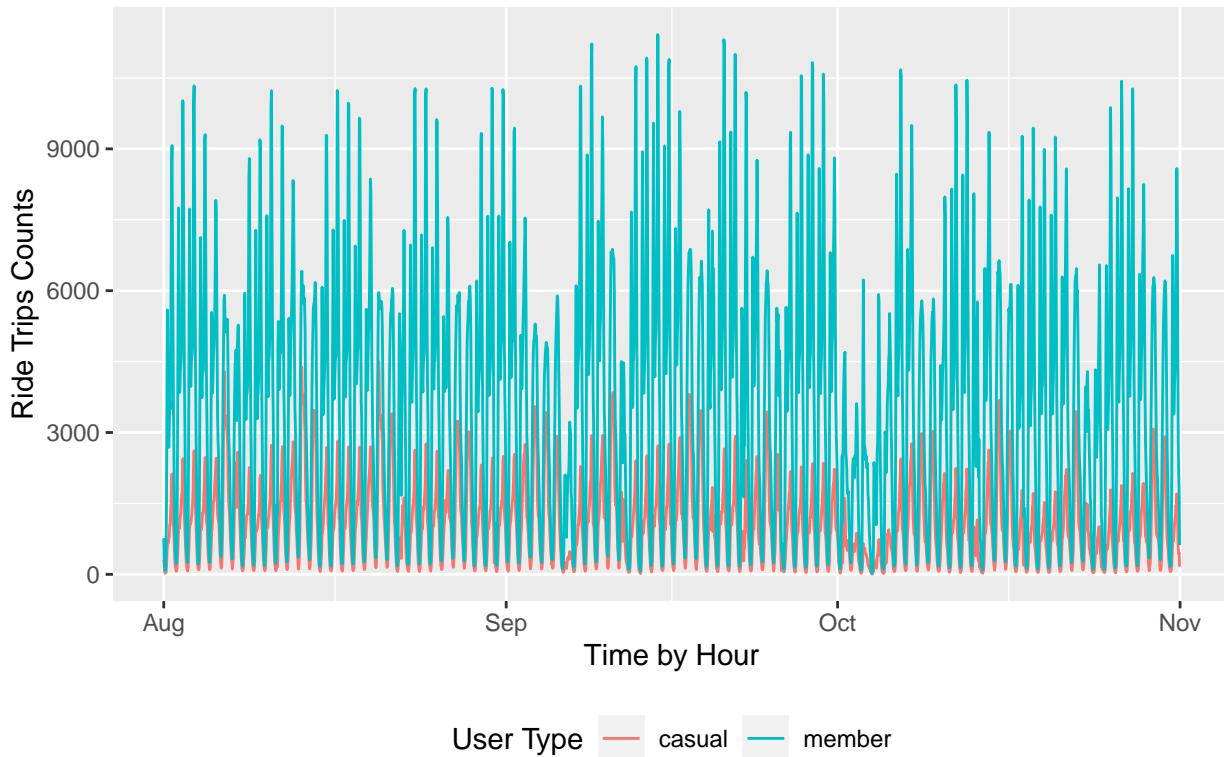
The count of bike trips are separated by user type – member and casual. With the separation by user type, two distinct patterns emerge of bike use over the course of the day and over the course of a week. The member trips are more likely to follow the workday pattern of spikes in the morning and evening as individuals are traveling to or from work. The casual users show a pattern not necessarily indicative of the workday but instead of tourism or recreational use. The member trips account for an overall higher volume of trips.

As seen in the chart “Median Number of Bike Trips,” the member counts show rush-hour spikes on weekdays whereas casual users do show higher counts around 5 p.m. and 6 p.m. on weekdays. The comparison of the two user groups also points to greater overall usage by members. For every day of the week, the average member counts per hour are greater than the casual users. On weekend days, both user groups show a pattern indicative of recreational use with a plateau of use during the middle of the day and without the distinct peaks found on the weekdays. Also, the higher usage by member users throughout the middle of the day may indicate even if an individual is a member, the primary reason may not be transportation to and from work.

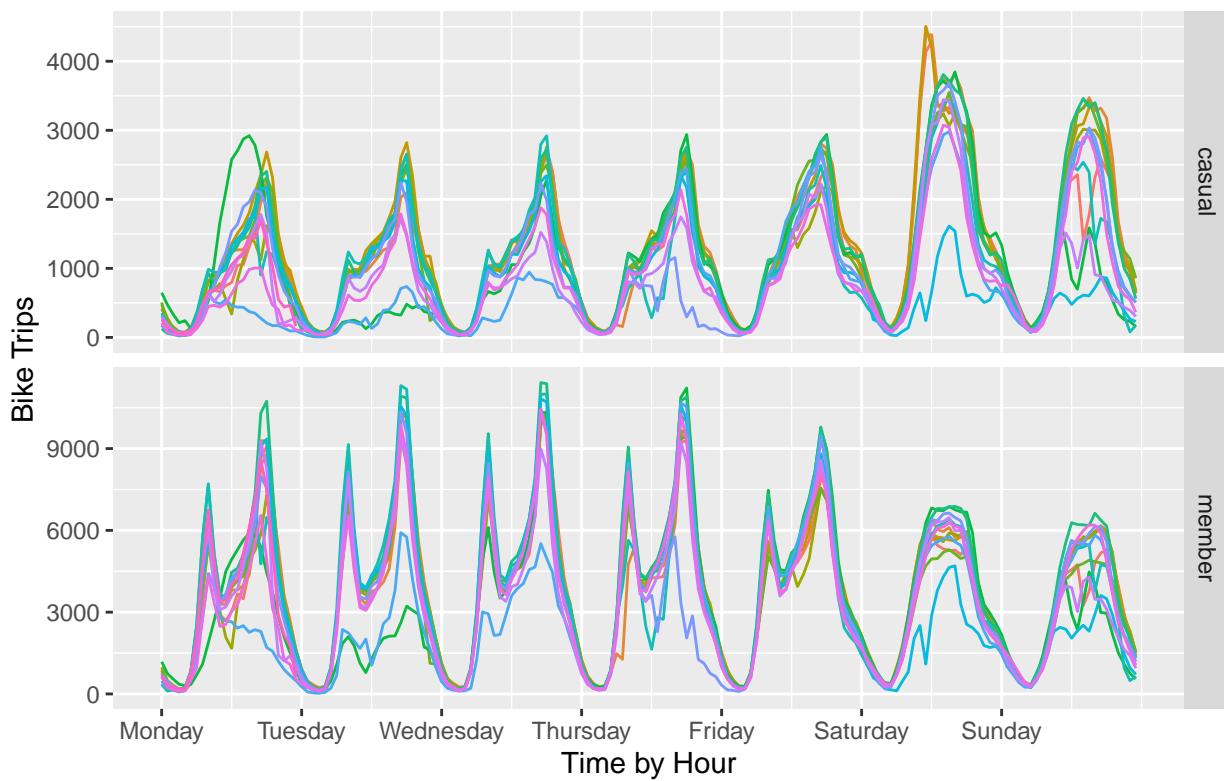
## Median Number of Bike Trips



## Ride Trips by Hour



## Seasonal plot: Weekly Trip Counts

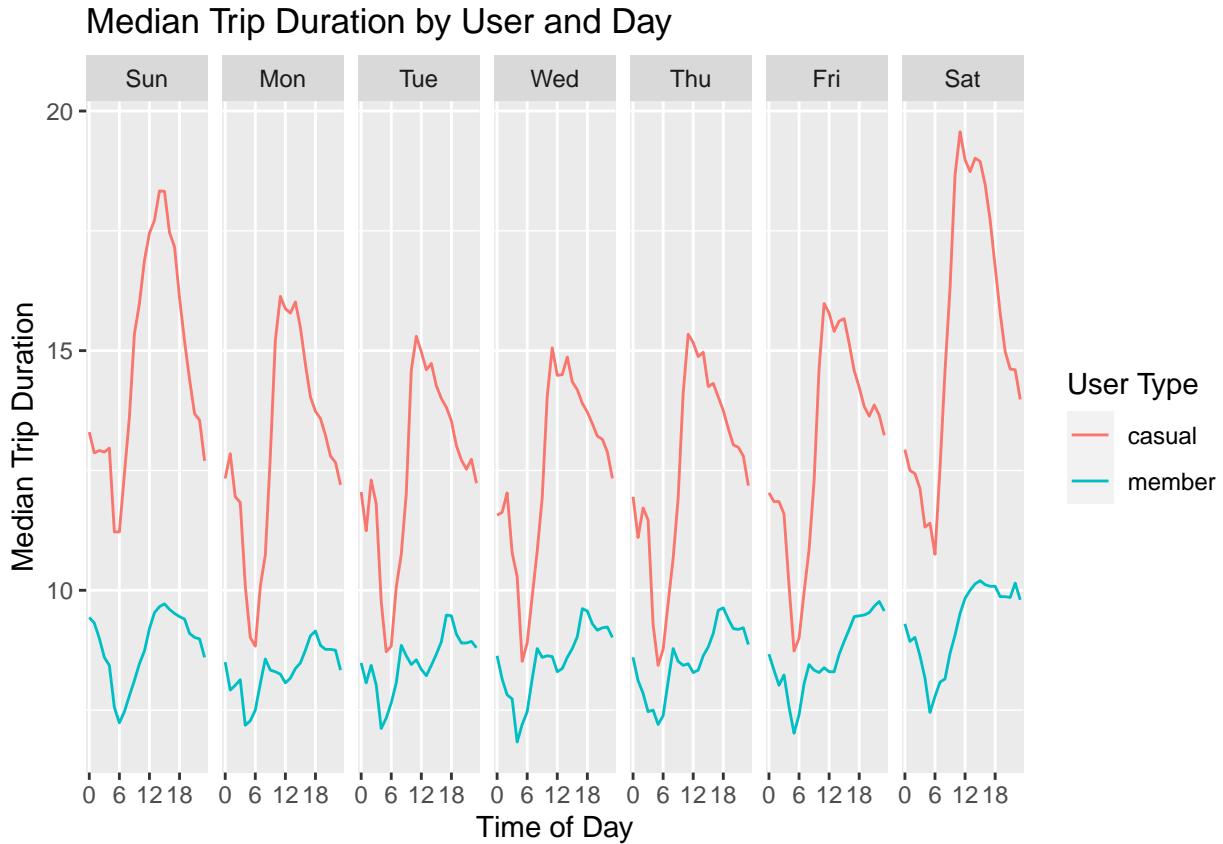


The time-series chart “Ride Trips by Hour” confirms the higher usage by members with a clear pattern of weekday volumes corresponding to transportation for work purposes. The casual users follow a daily pattern with increases toward the end of the week — Thursday through Saturday. The evening spike of casual users may indicate some casual individuals returning home from work or potentially tourists returning bikes in the early evening before a night out in the city. Poor weather conditions can directly impact the ridership on a given day as exemplified on the days with lower than expected member and casual counts. A thunderstorm on Sept. 6 and rain throughout early October contributed to the lower bike trip volumes visible in the chart.

The weekly seasonal plot “Seasonal plot: Weekly Trip Counts” denotes the same pattern week over week. Based on the plot, the bike trips show consistency every week based on members utilizing the bikes for work and casual users renting the bikes for recreational purposes.

### Duration of Bike Trips

Next, we evaluate the duration of bike trips to better understand longevity of individual bike unavailability along with the reason for the trip. As expected, the average bike trip for all users and at all times of day are below 30 minutes as the bike rental checkout is set for 30 minutes. Users will incur an additional fee beyond the base time limit.



The chart “Median Trip Duration by User and Day” shows a clear distinction between the user types. Member users tend to average bike trips of 10 minutes or less throughout the week, whereas the casual users have a greater range in average duration based on time of day and day of the week. The member users only average trips greater than 10 minutes during the afternoon and evening on Saturday while casual users typically average even longer trips of greater than 17 minutes on the weekend. Casual users tend to reach a peak of greater than 15 minutes on average every day of the week, particularly around lunch on weekdays.

We observe that members tend to have longer average trips during the morning and evening rush hours on

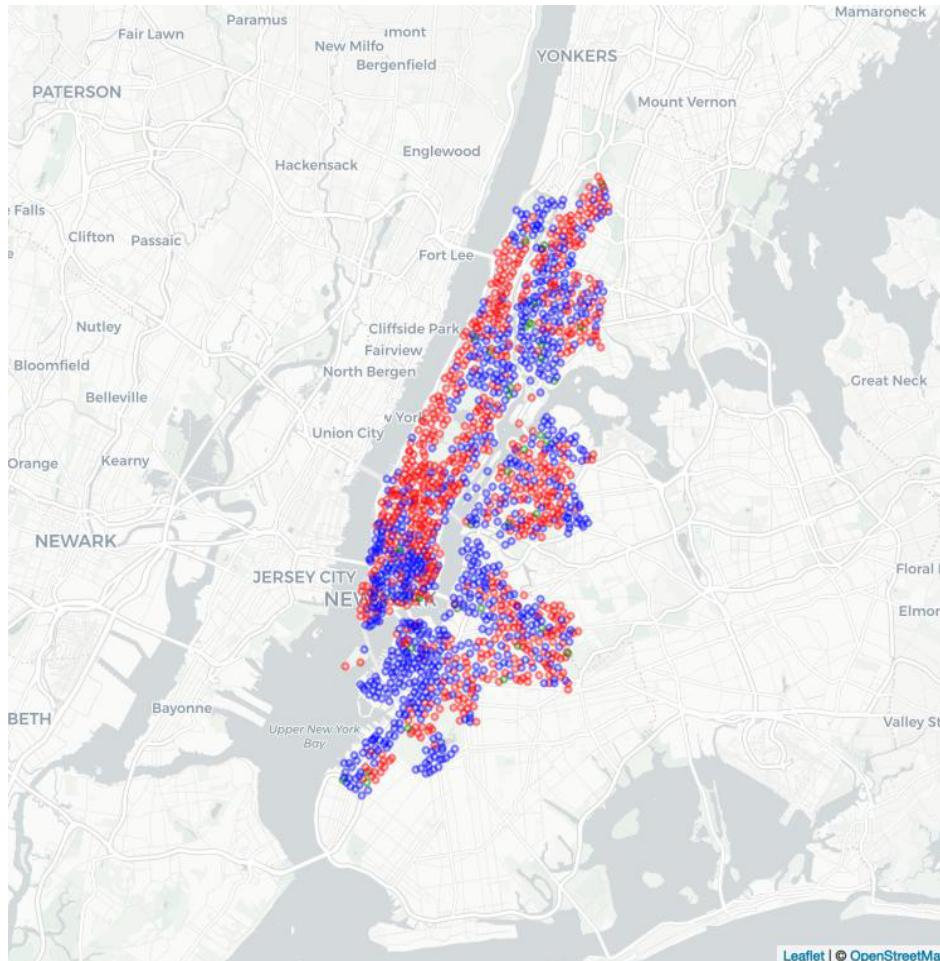
weekdays with a slight deviation on Friday evening as the weekend starts. The afternoon and evening hours of Saturday and Sunday show longer trips for members as likely the result of recreational use.

### Docking Station Surplus

After constructing a matrix of bike arrivals and departures for each NYC-based docking station for every 15-minute interval of August through October 2022, we calculate the overall surplus or shortage of bikes for each docking station. One caveat to note, the shortage of bikes can logically not fall below zero without the introduction of rebalancing throughout the bikeshare system. The following analysis confirms the practice of rebalancing across the bikeshare system occurs to ensure popular departure docking stations have bikes available despite the unequal number of arrivals.

## Overall Surplus/Shortage by Docking Station

Surplus: Blue -- Shortage: Red -- Even: Green



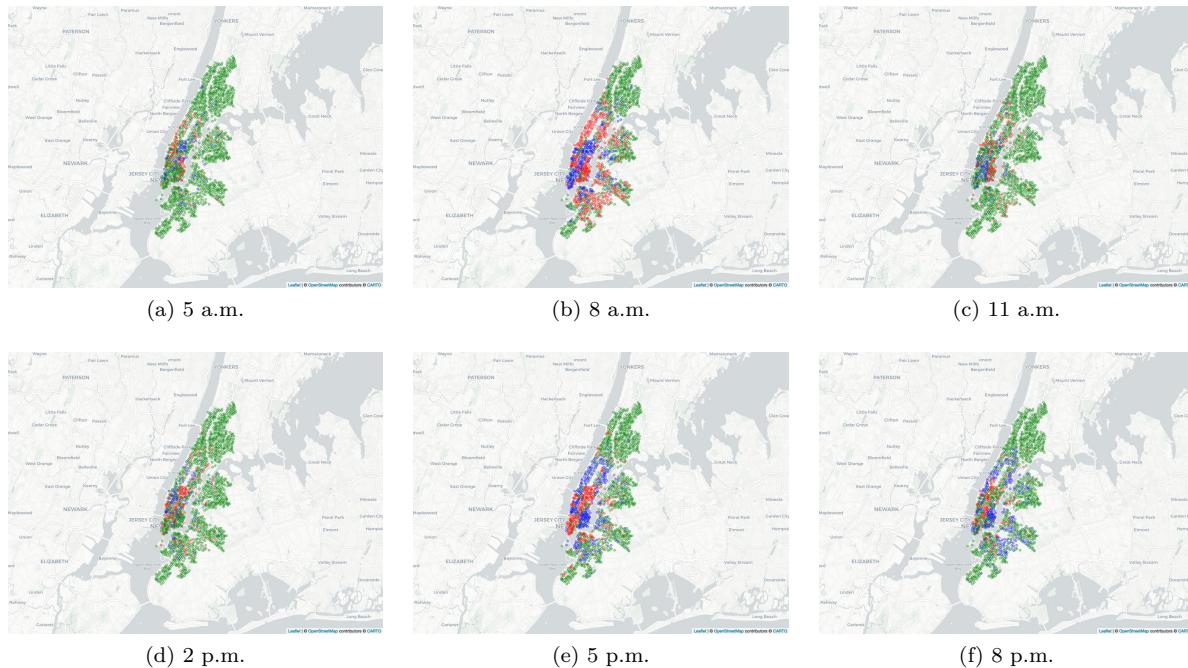
The plot of docking stations across New York City maps the location of every docking station along with a color to indicate a net positive, net negative or even amount of bikes for the given month. The blue

stations are net positive, and red stations indicate net negative while green stations are even for the entire three months. Of the 1,716 docking stations represented, 910 ended with a surplus, 771 with a shortage, and 35 with an even count. The map clearly shows broad sections of the city, primarily in Manhattan with the neighborhoods around Central Park with an overall shortage of bikes by docking station. The southern end of Manhattan along with the northern end and into the Bronx indicate surpluses at docking stations. To the east in Brooklyn and Queens, the surplus of bikes appears along the East River with shortages further away from Manhattan. In Brooklyn and Queens, surpluses occur in the more commercial and entertainment-friendly neighborhoods while the more outlying areas reveal a greater departure of bikes.

### Docking Station Surplus: Weekday Pattern

To better understand the daily flow of bikes, the average arrivals and departures across Wednesdays of the three-month period per docking station are plotted below by identified hour of the day in the plot “Weekday Pattern: Average Wednesday.” The selection of Wednesday, the day of highest use, provides a clear representation of weekday activity.

**Weekday Pattern: Average Wednesday**



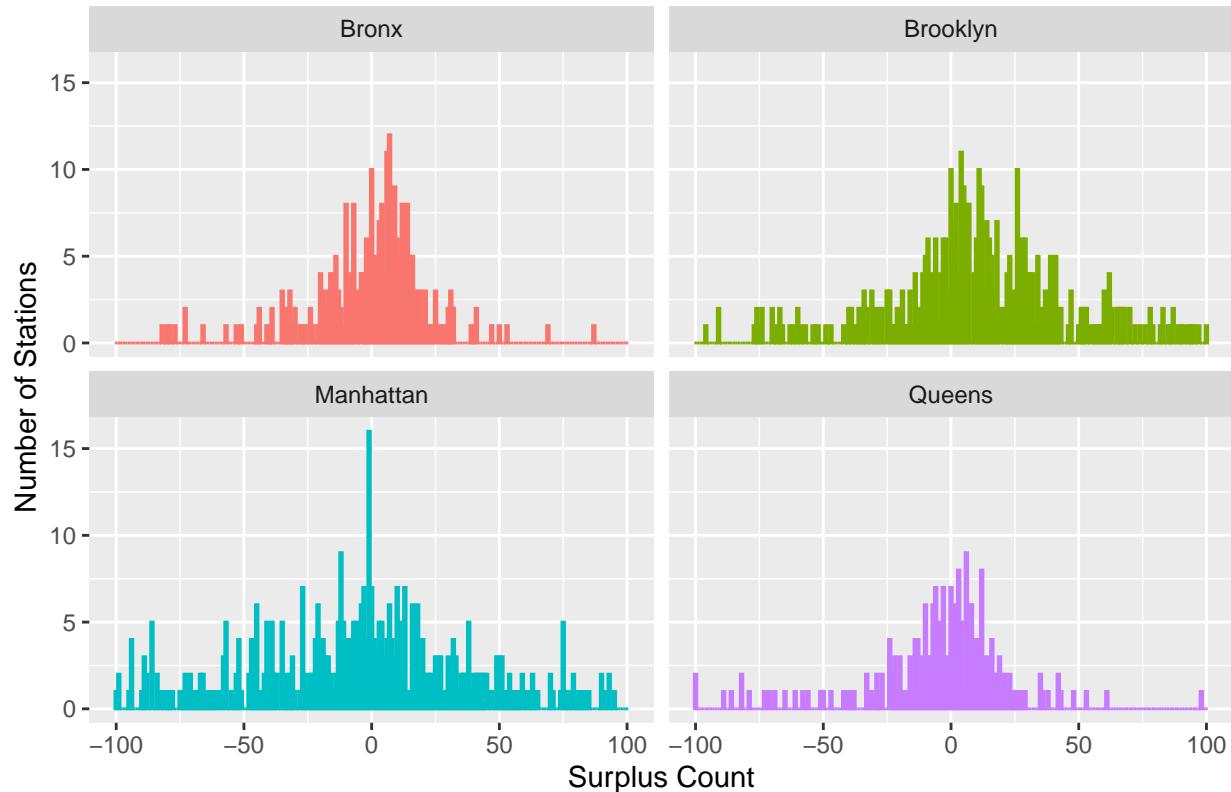
**Manhattan:** Starting at 5 a.m., most docking stations are colored green, indicating little movement of bikes at such an early hour. At 8 a.m., the docking stations in Midtown and the Financial District in Manhattan, two concentrated areas of commercial offices, are primarily blue as individuals arrive for work. Also at 8 a.m., red docking stations populate the more residential areas of the upper West Side and the East Village. At 11 a.m., most docking stations are green across the city as the morning rush has subsided. Later at 2 p.m., the plot remains similar to 11 a.m. as the lunch movement has subsided and before evening rush hour. Then at 5 p.m., the inverse of the 8 a.m. map appears. Now, Midtown and the Financial District areas are red representing the departure of employees from the commercial centers. Also at 5 p.m., blue docking stations color the Upper West Side and East Village as individuals return home from work. Finally, during the 8 p.m. hour, the pattern remains similar to the 5 p.m. plot as bike movement continues away from commercial areas toward residential areas with an increasing number of green docking stations throughout the city.

**Brooklyn and Queens:** In less dramatic fashion than Manhattan, the 8 a.m. panel shows movement from the outlying areas in red toward the East River and subway station locations in blue. The evening panels at 5 p.m. and 8 p.m. capture the inverse of the morning movement with more blue docking stations in the outlying areas as more bike arrivals occur in the residential areas.

### Surplus by Borough

Given the visible distinctions on the map of where bike surpluses and shortages occur across New York City, we evaluate the shortage and surplus by borough to understand bike availability at the borough level.

**Station Surplus by Borough**

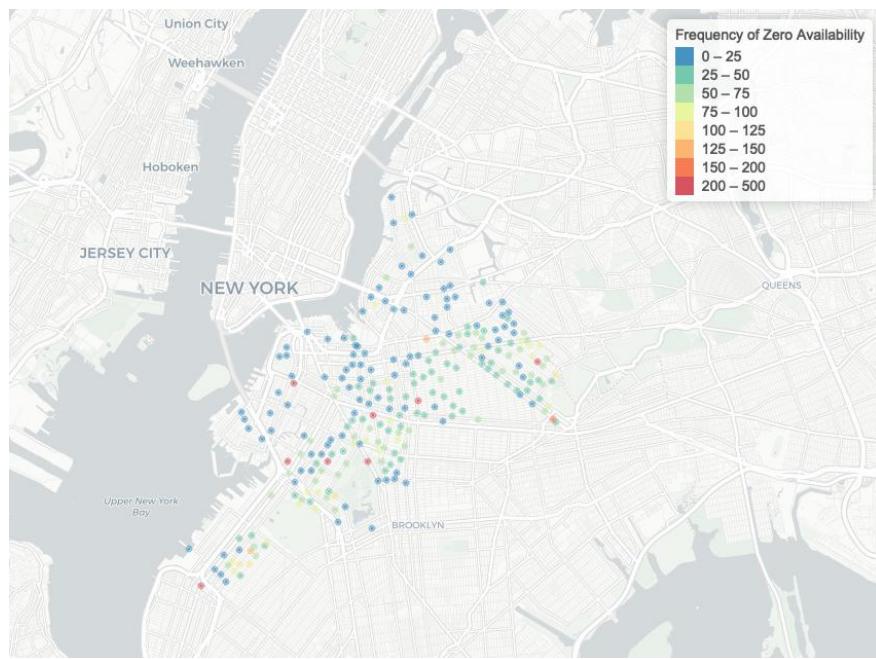


The plot “Station Surplus by Borough” denotes a near normal distribution for the four boroughs included in the dataset — the Bronx, Brooklyn, Manhattan, and Queens. The balanced distribution across the four NYC boroughs demonstrates that bike trips are contained within a borough. With average duration less than 10 minutes for member users and less than 20 minutes for casual users, the distance traveled for all bike trips is likely less than three miles. The 30-minute base rental rate dictates a limited travel distance inhibiting users from traveling across boroughs via the bikeshare system.

### Zero Bike Availability

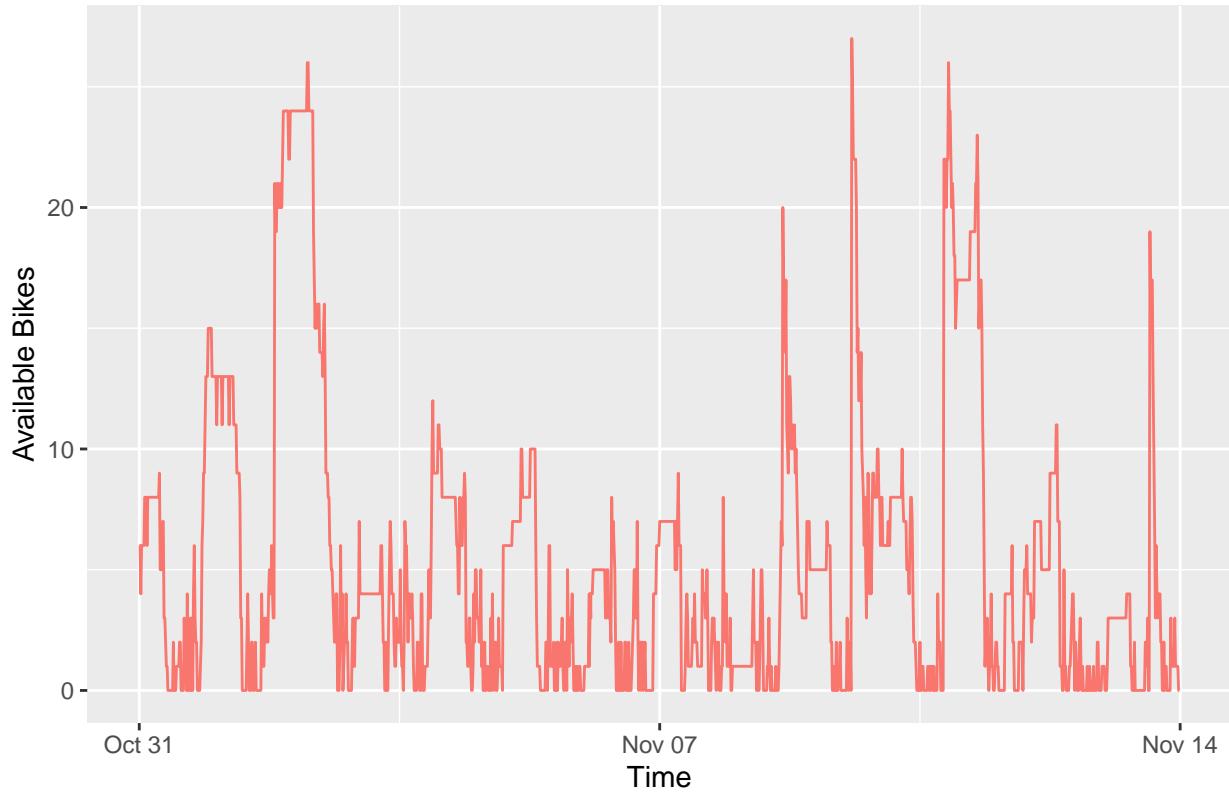
The map plot “Zero Availability by Docking Station” shows the docking stations with frequency of zero-bike availability in Brooklyn. Most docking stations have a lower frequency of 50 or less occurrences across the 1,344 15-minute intervals of the two week period. We do notice a number of red stations indicating high frequency of zero available bikes. These stations could be considered for greater rebalancing.

## Zero Availability by Docking Station



### Rebalancing Example

#### Docking Station 3582



The line chart “Docking Station 3582” depicts the number of available bikes every 15 minutes for docking

station 3582 in Crown Heights Brooklyn. The chart clearly shows four spikes to 20 or more available bikes occurring within the two-week span of Oct. 31 to Nov. 13. These sudden increases, examples of rebalancing, are inconsistent and always return to under 10 available bikes. This chart indicates the departure usage is driven by the available bikes but the arrival of bikes remains low during this time span. The term for greater availability driving higher usage is called induced demand.

According to the Citi Bike operating report for September 2022 (latest available as of report submission), the Citi Bike staff rebalanced a total of 70,117 bikes during the month. The operating report calculates an average bike fleet in September as 24,514.0 with 24,327 bikes in the fleet on the last day of the month. Given the total number of rebalanced bike over 70,000 for the month and an average of 24,514 bikes available per day, almost 10% of all bikes are rebalanced daily. As seen in the previous visualizations, an even distribution of bikes does not occur and must be addressed by the operators to ensure daily bike availability.

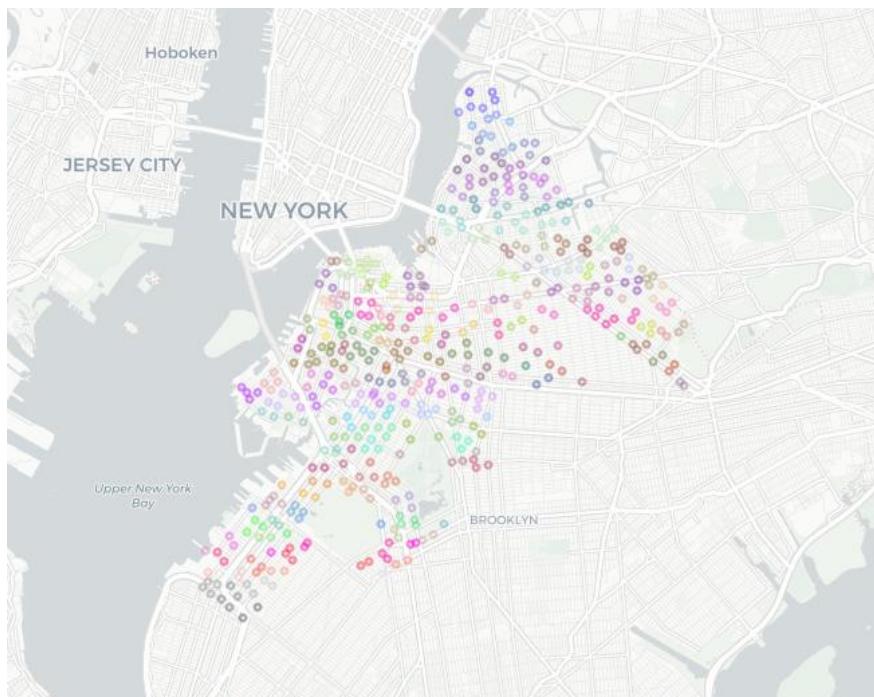
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## Hierarchical Clustering

With over 1,700 stations and a walking distance of 400 meters (or one quarter of a mile), the clustering of all NYC docking stations resulted in over 700 unique clusters. The high volume of clusters caused vector memory issues in RStudio. In order to continue the research approach, the stations under consideration were decreased to one borough – Brooklyn. Brooklyn contains 474 docking stations. Using the hierarchical clustering from the `stats` R library, with a distance cutoff of 400 meters, the result is 213 clusters or a little over 2 docking stations per cluster. This distance-based technique establishes quarter-mile based clusters informed by an acceptable walking distance as one variable of input to the regression prediction models. The map plot shows the docking stations colored by cluster number.

- **Borough:** Brooklyn
- **Docking Stations:** 474
- **Clusters:** 213 (2.23 stations/cluster)

**Docking Stations Colored by Cluster**

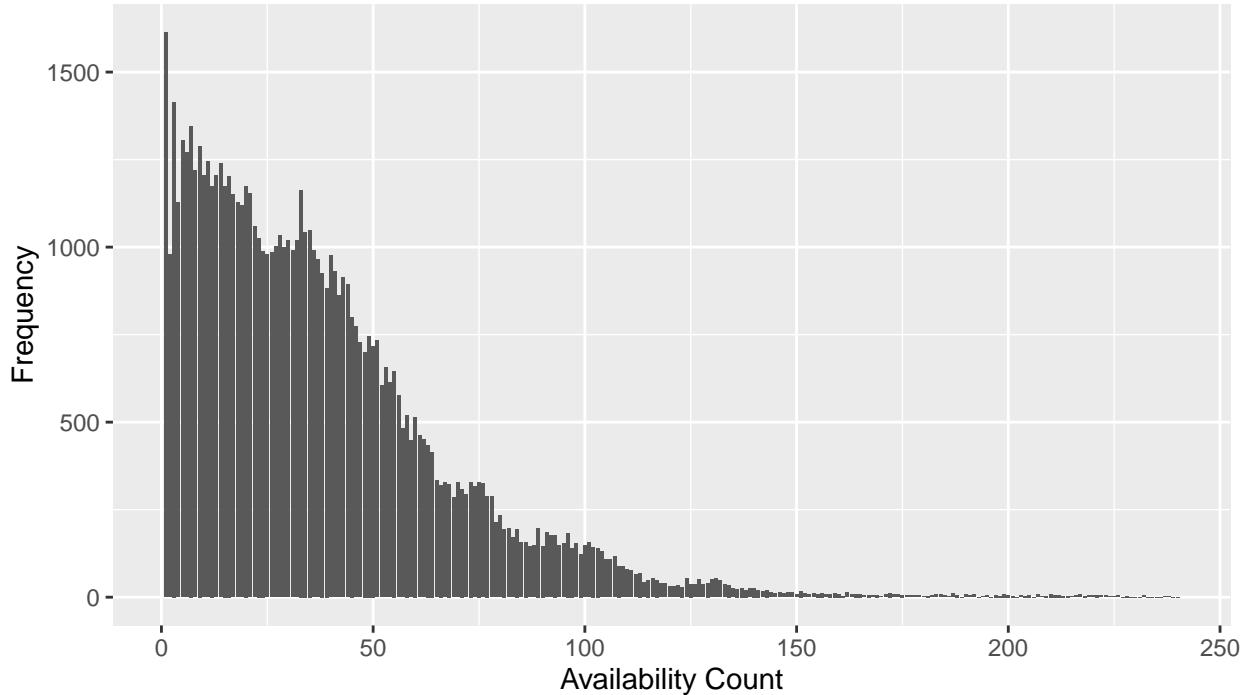


## Bike Availability by Cluster

The histogram below shows the frequency of bike availability counts across all the Brooklyn clusters for each one-hour interval for the two-week timespan. The value of zero is the most frequent value followed by two. A plateau is visible around 25 which marks a station capacity. A similar plateau also occurs around 60, close to double the single station capacity which would be expected given most clusters are two docking stations. The plot confirms the likelihood of zero bike availability.

The prediction model ultimately based the independent variable time on the hour of the day, hence the transition from 15-minute intervals to one-hour intervals in the research and analysis.

**Frequency of Hourly Available Bike Counts for Brooklyn Clusters**



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## Count Data Regression Modeling

To predict the bike availability count by cluster, we apply count data regression models. We selected Generalized Linear Models based on Poisson, Quasi-Poisson, Negative Binomial and Zero-Inflated algorithms. The availability data meets most of the Poisson regression criteria. The response variable is a count per unit of time. The observations are independent. Unfortunately, the variance is greater than the mean, which indicates overdispersion in the data. The mean of the bikes available by cluster is 36.34474 and the population variance over the dataset is 908.1704 indicating overdispersion exists. The range of available bikes by cluster is 0 to 237. Due to overdispersion, we selected Negative Binomial and Quasi-Poisson as base algorithms in addition to Poisson. The Zero-Inflated algorithm was chosen based on the previous observation in which zero-bike availability is the most common value across all the docking-station clusters.

For evaluating the models, the two full weeks of bike availability data spanning Oct. 31 through Nov. 13 are partitioned into a training set of 75% and a test set of 25%. Given the common, yet inconsistent occurrences of rebalancing identified previously, we decided to not impute the instances of rebalancing, but instead keep the data accurate in an attempt at a more accurate model. The dataset follows a time series pattern but in

order to predict a specific day and time of the week agnostic of date, regression models for count data are used instead of time-series forecasting.

The model inputs mimic a map-based application in which a user selects a point on a map along with the type of day and time to receive a prediction of the bikes available at that future date, time, and location. Based on the user-provided longitude and latitude, a nearest neighbor search is performed to identify the nearest docking station. This translation of the longitude and latitude to the corresponding cluster of the nearest-neighbor docking station is the input to the model. The categorical variable type of day, weekday or weekend, was chosen due to the differing usage patterns on weekdays and weekends. Within each category, weekday and weekend, the similarities allowed us to simplify the model to two values instead of accounting for each day. The time of day is converted to the start of the hour. Models were constructed using 15-minute intervals, but due to computing system constraints, the time interval selected was one hour. The dependent variable is the available bike count with the floor function applied to ensure a whole number prediction.

- Independent variables
  - Cluster identifier converted from longitude and latitude (categorical)
  - Type of day: “Weekday” or “Weekend” (categorical)
  - Time of Day in 1-hour intervals (categorical)
- Dependent variable
  - Available number of bikes (integer)

## Generalized Linear Models for Count Data

For the heart of the prediction model, we apply five distinct models to the availability counts by cluster. First, we use Poisson from the `stats` library followed by Quasi-Poisson, also from the `stats` library. Then we attempt Negative Binomial from the `MASS` library and finally, Zero-inflated, with a Poisson base and a Negative-Binomial base, relying on the `pscl` library. We trained on the 75% sample, 53,853 instances, and tested on the remaining 25% of the data, 17,715 instances.

**Poisson Model:** The Poisson model is a generalized linear model for count data with the assumption that the variance is equal to the mean. Despite the indication of overdispersion due to the much greater variance than mean, we attempt the Poisson model first.

The `dispersiontest` function from the `AER` library indicates a dispersion of 3.8466699 in the Poisson model. A value over 1 confirms overdispersion.

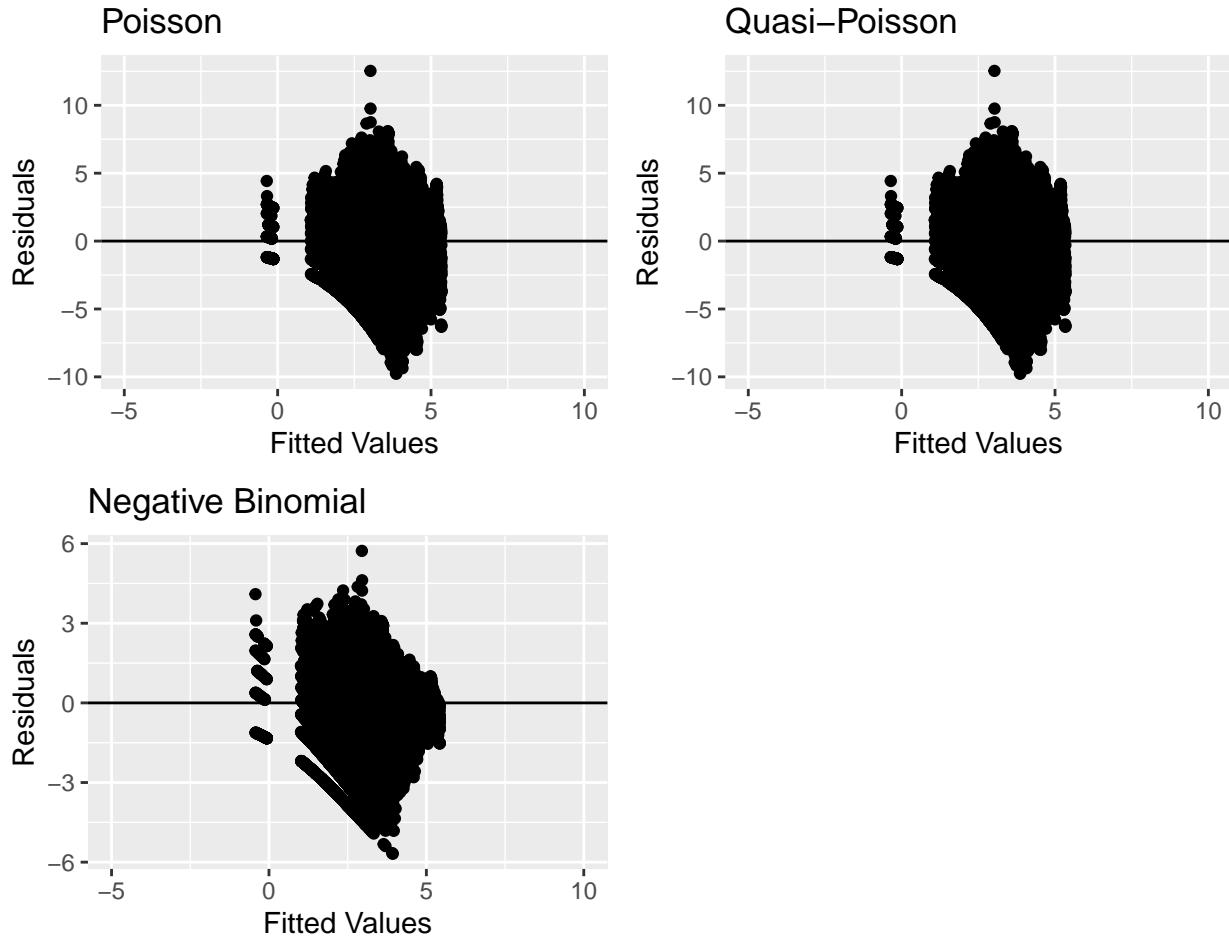
**Quasi-Poisson Model:** The Quasi-Poisson Model is a generalized linear model for count data to address an overdispersed count variable in which the variance is a linear function of the mean.

**Negative Binomial Model:** The Negative Binomial model is a generalized linear model for count data in which the variance is greater than the mean, and the variance is a quadratic function of the mean.

Model	Deviance	Degrees.Freedom	AIC
Poisson	219859.7	53616	487809.6
Quasi-Poisson	219859.7	53616	NA
Negative Binomial	66131.4	NA	414441.1

Due to the high number of clusters and hourly intervals used for the regression models, the models created a large volume of dummy variables. For the variable `cluster`, 212 variables are created, for the variable `time`, 23 variables are generated, and for `day` one additional variable is created. This variable expansion makes the model variables difficult to assess individually as the model only has three input categorical variables.

The results of the first two models show identical results of deviance and degrees of freedom for Poisson and Quasi-Poisson. The Negative Binomial model did produce a lower AIC than the Poisson model indicating a slightly better model.



The plots of the residuals versus the fitted values for Poisson, Quasi-Poisson, and Negative Binomial each indicate heteroscedasticity. The evidence of heteroscedasticity shows increasing variance as the fitted values increase. The Poisson and Quasi-Poisson appear identical while the Negative Binomial plot is also similar.

**Zero-Inflated Model:** A Zero-Inflated Model builds a model for a distribution that allows for frequent zero-value observations. The Zero-Inflated models used in this research use a base of Poisson (ZIP) and Negative Binomial (ZINB). The summary statistics and plots for the Zero-Inflated models are not included as the summary objects did not contain the same attributes as the previous three models.

## Model Results

To evaluate the five models, we made the selection based on the Root-Mean-Square-Error (RMSE), Mean Average Error (MAE), and Mean Absolute Scaled Error (MASE) along with the count of predictions greater than zero when the actual value was zero, noted here as `Missed.Zero`. The Zero-Inflated Poisson based model performed the best according to RMSE, MAE, and MASE followed by Poisson, Quasi-Poisson, and then the Zero Inflated Negative Binomial model and finally Negative Binomial. Assessing the missed zero column, we notice Poisson, Quasi-Poisson and Negative Binomial with the fewest missed zeros at 263 followed by the Zero-Inflated models with 280 missed zeroes each. Overall, the performance of the models falls in a small range with RMSE ranging in 11.2482 to 12.0320. These results show an average distance of approximately 11 between the predicted values and the actual values from the dataset. As the plot of bike availability count frequency by cluster showed, zero was the highest frequency but did not represent an outlying volume within the frequency distribution. The zero-inflated models may have performed worse at correctly predicting zeroes because the zero frequency was not inflated as compared to the other values.

Model	RMSE	MAE	MASE	Missed.Zero
Zero-Infl. (Poisson)	11.2482	8.0648	0.2649	280
Poisson	11.3075	8.1143	0.2665	263
Quasi-Poisson	11.3075	8.1143	0.2665	263
Zero-Infl. (NB)	11.8260	8.3998	0.2759	280
Negative Binomial	12.0320	8.5401	0.2805	263

In the end we selected the Poisson model because it resulted in the second best RMSE, MAE, MASE and had the fewest Missed.Zero counts despite the variance being greater than the mean. The Poisson regression equation is presented for the selected model.

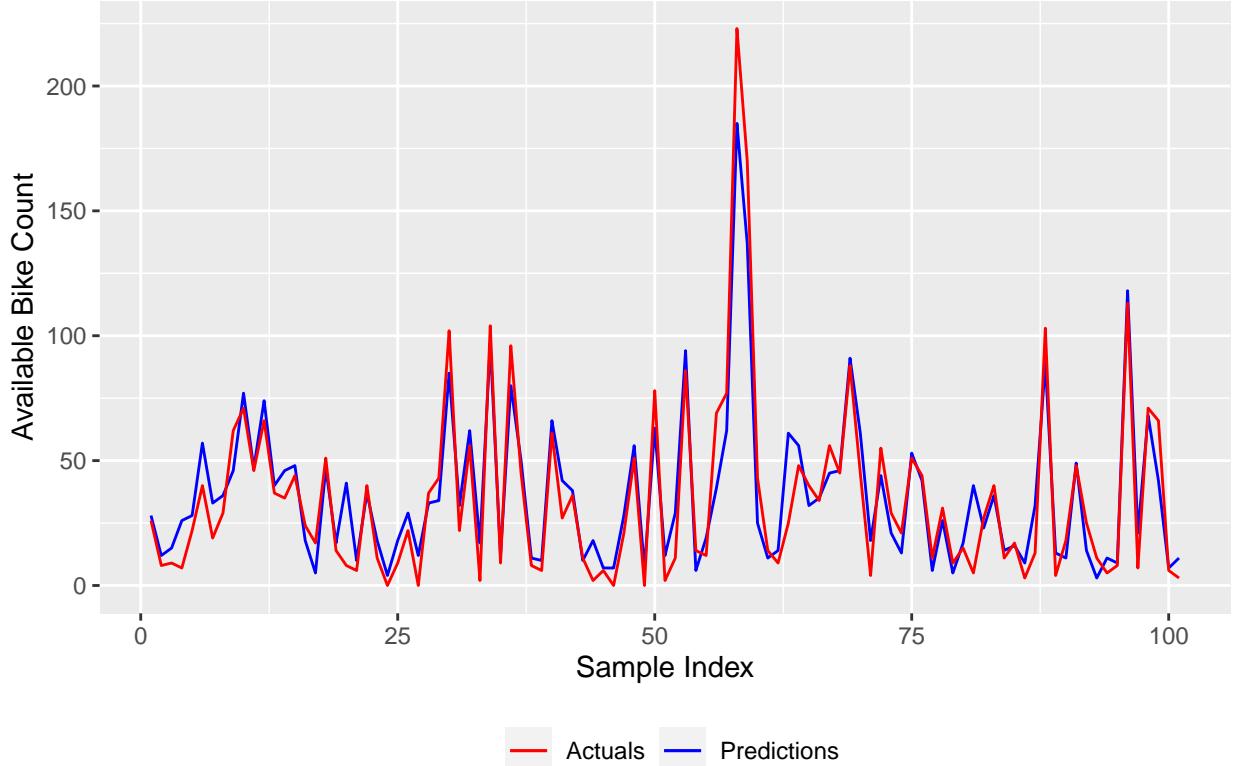
Selection: Poisson regression equation

$$\log(bikes) = 3.9063 + \beta_1 \cdot cluster + \beta_2 \cdot time + \beta_3 \cdot day \quad (1)$$

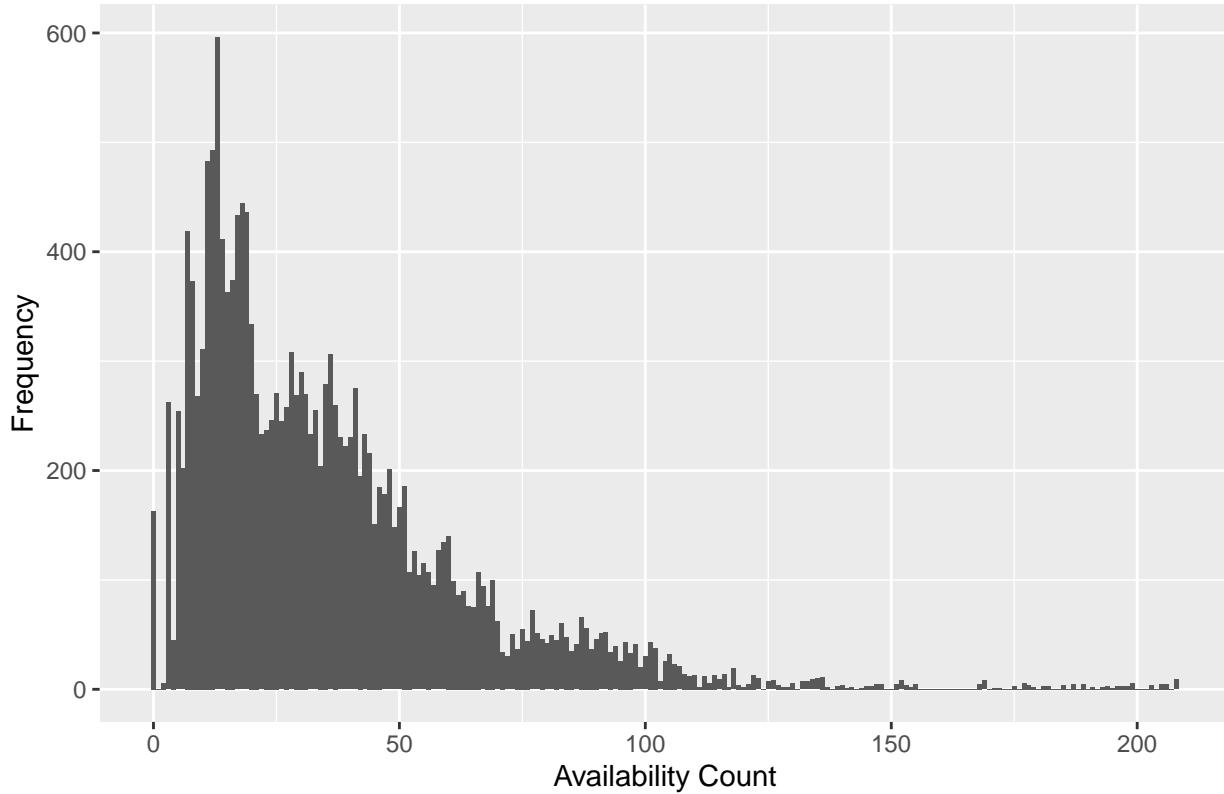
### Model Results Visualizations

The test data dataset consisted of over 17,000 rows for prediction. To better understand the predictions from the Poisson model against the actual test data values, the plot displays a subset of 100 predictions and the corresponding actual values. The actual values in red extend to the 0 axis while the blue line does not reach the 0 axis as often, indicating the inability of the model to accurately predict the true zero values. Upon visual inspection, the lines for prediction and actual values do appear consistent.

### Availability Counts and Predictions



## Frequency of Hourly Available Bike Count Predictions



The above histogram shows the frequency of available bike predictions for the test dataset. Overall, the distribution is similarly right skewed to the histogram of actual availability counts by cluster. This histogram pinpoints the lack of predictions below 10 bikes and thus an opportunity for better accuracy at lower counts.

Other model considerations: Elevation of the cluster as an independent variable was initially included, as anecdotally, stations with higher elevations have fewer returned bikes. The elevation predictor resulted in little significance to the model and thus was omitted. Also considered, but not used was the time-series forecasting model approach. As the forecasting did not allow for instance predictions, we decided not to include the forecasting approach in the final report.

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### Real-World Prediction Proof of Concept

With the intention of making the model functional in the real world, a simple R function was written to predict the number of bikes available based on the user-friendly inputs. First, the longitude and latitude are translated into a cluster identifier based on a nearest neighbor search of the docking stations. Then, with the cluster identifier and other user inputs, the GLM regression model is executed to predict the number of available bikes. The result of three trials indicate the number of available bikes and cluster number. The neighborhoods provided are displayed to give the user reference of the longitude and latitude entered. The user-friendly inputs:

- Latitude and longitude (location on map)
- Hour of the day
- Weekday or Weekend

Neighborhood	Longitude	Latitude	Time	Day	Prediction	Cluster
Crown Heights	-73.9609	40.6736	22:00:00	WDAY	13	58
Williamsburg	-73.9617	40.7192	18:00:00	WKND	57	201
Sunset Park	-74.0051	40.6434	17:00:00	WDAY	5	10

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## Conclusion

Using the Citi Bike dataset for NYC-based trips in August through October 2022, we identified a consistent pattern of use dependent on time of day and day of the week. The pattern persists week over week for the months under review. The majority of users are member which indicates the availability of bikes will be dependent on work schedules during weekdays. The surplus and shortage count of bikes by docking station denotes the uneven flow of bikes in some neighborhoods of New York City. The surplus and shortage counts confirm the practice of rebalancing by Citi Bike to ensure availability of bikes despite revealing a high frequency of zero bike availability at certain docking stations.

We constructed a model to predict Citi Bike availability in Brooklyn with the possibility of extension across all of New York City. Using data science principles and common model algorithms, a prediction model was constructed for a user-friendly interaction. Based on location, day of the week, and time of day, the combination of a hierarchical clustering and Poisson count model algorithm predict the number of available Citi Bikes within a quarter mile. In assessing the GLM count data models, the Poisson model was selected based on the model metric scores and ability to accurately predict zero availability. The false positive of bike availability when zero bikes available would greatly impact user experience and thus played a key factor in the model selection decision. The overall prediction model provides a potential real-world application for individuals planning transportation options ahead of time across New York City.

## Future Work

Given the functional prediction model, a future consideration is the deployment of the prediction model as a simple website or smartphone app to get the model into users' hands for real-world feedback. With the use of the model on a smartphone, the location input could come directly from the GPS location of the device to ensure a user-friendly experience.

Due to the computing system constraints and resulting model decisions, we believe several opportunities can improve the model accuracy. An auto-regressive algorithm may provide a higher accuracy of zero availability predictions given the time measurement of the dataset. We recognize a prediction of 10 available bikes instead of 8 would not be the headache to a user, whereas a prediction of 2 available bikes instead of 0 would be quite frustrating. Also, basing the model on 15-minute intervals instead of the one-hour intervals would also provide greater granularity to the prediction model. The researchers understand the limitation yielded by the two weeks of availability data, so to improve the model, we anticipate a greater timeframe of availability data would in turn improve the model.

Finally, an obvious next step would be the inclusion of all the docking stations across New York City. With the majority of docking stations in Manhattan, a model of the entire city would provide value to a greater audience. In conjunction with the addition of all docking stations, a real-time clustering approach to identify all docking stations within a quarter mile of the chosen location at the time of use would be of greater benefit.

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## References

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- Wang, Xize, Greg Lindsey, Jessica E. Schoner, and Andrew Harrison. 2016. “Modeling Bike Share Station Activity: Effects of Nearby Businesses and Jobs on Trips to and from Stations.” *Journal of Urban Planning and Development* 142 (1). [https://doi.org/10.1061/\(asce\)up.1943-5444.0000273](https://doi.org/10.1061/(asce)up.1943-5444.0000273).
- Zhou, Xiaolu, Mingshu Wang, and Dongying Li. 2019. “Bike-Sharing or Taxi? Modeling the Choices of Travel Mode in Chicago Using Machine Learning.” *Journal of Transport Geography* 79: 102479. <https://doi.org/10.1016/j.jtrangeo.2019.102479>.

## Data Sources

- <https://ride.citibikenyc.com/system-data> (Bike trips)
- <https://ride.citibikenyc.com/system-data/operating-reports> (Rebalancing counts)
- <https://github.com/MobilityData/gbfs/blob/master/gbfs.md> (Availability API)
- <https://data.cityofnewyork.us/City-Government/2010-Neighborhood-Tabulation-Areas-NTAs-/cpf4-rkhq> (NTA neighborhoods)

## Appendix with Code

```
knitr::knit_hooks$set(time_it = local({  
  now <- NULL  
  function(before, options) {  
    if (before) {
```

```

# record the current time before each chunk
now <- Sys.time()
} else {
  # calculate the time difference after a chunk
  res <- difftime(Sys.time(), now)
  # return a character string to show the time
  paste("Time for this code chunk to run:", res)
}
}
}))
```

```
#knitr::opts_chunk$set(time_it = TRUE)
```

```
# Required packages
library(tidyverse)
library(ggplot2)
library(skimr)
library(lubridate)
library(fpp3)
#library(assertthat)
#library(igraph)
#library(ggraph)
#library(ggmap)
library(leaflet)
library(rgdal)
library(RColorBrewer)
library(jpeg)
library(data.table)
library(MASS)
library(RANN)
library(geosphere)
library(broom)
library(AER)
library(Metrics)
library(pscl)
library(kableExtra)
library(cowplot)
```

```
# Create additional columns of pertinence
# weekday, day of the month, trip duration in minutes, start hour
citibike_202208 <- fread("data/202208-citibike-tripdata.csv", data.table=FALSE, check.names=TRUE)
citibike_202209 <- fread("data/202209-citibike-tripdata.csv", data.table=FALSE, check.names=TRUE)
citibike_202210 <- fread("data/202210-citibike-tripdata.csv", data.table=FALSE, check.names=TRUE)

#citibike <- fread("data/202210-citibike-tripdata.csv", data.table=FALSE, check.names=TRUE) %>%
citibike <- bind_rows(citibike_202208, citibike_202209, citibike_202210) %>%
  mutate(day = factor(mday(ymd_hms(started_at))),
        start.hour=factor(hour(ymd_hms(started_at))),
        weekday = lubridate::wday(ymd_hms(started_at), label=TRUE, abbr=TRUE),
        trip.duration = as.numeric(difftime(ended_at,started_at,units="mins")),
        member_casual = factor(member_casual)) %>%
  rename(ride.id=ride_id, rideable.type=rideable_type, started.at=started_at,
         ended.at=ended_at, start.station.name=start_station_name, start.station.id=start_station_id,
```

```

    end.station.name=end_station_name, end.station.id=end_station_id, start.lat=start_lat,
    start.lng=start_lng, end.lat=end_lat, end.lng=end_lng, member.casual=member_casual)

# Figure out abandoned and label them
citibike$end.station.name[citibike$end.station.name == ''] <- "Abandoned"
citibike$end.station.id[citibike$end.station.id == ''] <- "ABAN"

# Output DF if needed
head(citibike)

# Trip by weekday by segment by time of day
citibike %>%
  group_by(day, member.casual, start.hour) %>%
  summarize(n=n(),
            weekday=weekday[1]) %>%
  group_by(weekday, member.casual, start.hour) %>%
  summarize(n.m=mean(n)) %>%
  ggplot(aes(x=start.hour, y=n.m, fill=weekday)) +
  geom_bar(stat='identity') +
  labs(x='Time of Day',
       y='Number of Trips',
       title='Median Number of Bike Trips') +
  facet_grid(weekday~member.casual) +
  theme(axis.text.x = element_text(size=8, angle=90),
        legend.position = 'none')

citibike$started.at.ts <- as_datetime(as.character(citibike$started.at))

citibike_by_hour <- citibike %>%
  mutate(hour=lubridate::floor_date(started.at.ts, "1 hour")) %>%
  group_by(hour, member.casual) %>%
  summarize(cnt=n())
#citibike_by_hour

citibike_by_hour_ts <- citibike_by_hour %>%
  as_tsibble(index=hour, key=c(member.casual))
#citibike_by_hour_ts

autoplot(citibike_by_hour_ts, cnt) +
  labs(title = "Ride Trips by Hour",
       x = "Time by Hour",
       y = "Ride Trips Counts") +
  guides(colour = guide_legend(title = "User Type")) +
  theme(legend.position="bottom")
citibike_by_hour_ts %>%
  gg_season(cnt, period = "week") +
  labs(x = "Time by Hour",
       y = "Bike Trips",
       title = "Seasonal plot: Weekly Trip Counts") +
  theme(legend.position="none")
citibike %>%
  filter(member.casual %in% c('member', 'casual')) %>%
  group_by(weekday, start.hour, member.casual) %>%

```

```

summarize(med.duration=median(trip.duration)) %>%
ggplot(aes(x=start.hour, y=med.duration, group=member.casual,
           color=member.casual
#               , linetype=member.casual, shape=member.casual
)) +
#geom_point(size=2) +
geom_line(size=0.5) +
facet_wrap(~weekday, nrow=1) +
labs(x='Time of Day',
     y='Median Trip Duration',
     title = "Median Trip Duration by User and Day",
     color='User Type') +
scale_x_discrete(breaks=c(0,6,12,18))
# Create table of start to end station IDs
stations_cols <- citibike %>%
  dplyr::select(start.station.id, end.station.id)
stations_table <- as.data.frame((table(stations_cols)))

stations_table <- stations_table %>%
  filter(Freq > 0)

stations_table_order <- stations_table[order(-stations_table$Freq),]

stations_table_dif <- stations_table_order %>%
  filter(as.character(start.station.id) != as.character(end.station.id))

# Create table of start to end station IDs
stations_cols <- citibike %>%
  dplyr::select(start.station.id, end.station.id)
stations_table <- as.data.frame((table(stations_cols)))

stations_table <- stations_table %>%
  filter(Freq > 0)

stations_table_order <- stations_table[order(-stations_table$Freq),]

stations_table_dif <- stations_table_order %>%
  filter(as.character(start.station.id) != as.character(end.station.id))

stations_table_dif1 <- stations_table_dif
stations_table_dif2 <- stations_table_dif

# Added all=TRUE to account for one-sided counts
stations_table_dif_merge <-
  merge(stations_table_dif1,
        stations_table_dif1,
        by.x=c('start.station.id','end.station.id'),
        by.y=c('end.station.id','start.station.id'), all = TRUE)

# Set the NA (one-sided trips) to count of 0
stations_table_dif_merge[is.na(stations_table_dif_merge)] <- 0

stations_table_dif_merge$surplus <- stations_table_dif_merge$Freq.y - stations_table_dif_merge$Freq.x

```

```

stations_table_dif_merge <- stations_table_dif_merge[order(-stations_table_dif_merge$surplus),]

# Remove rows with start station id equal to ABAN for abandoned, those are a result of the merge all=TRUE
stations_table_dif_merge <- stations_table_dif_merge %>% filter(start.station.id != 'ABAN')

# Want to identify the surplus (or not) by station for the month
station_surplus_count <- stations_table_dif_merge %>%
  group_by(start.station.id) %>%
  summarize(surplus.sum=sum(surplus))

station_surplus_count <- station_surplus_count[order(-station_surplus_count$surplus.sum),]
colnames(station_surplus_count)[1] <- "station.id"

# Extract just the end station Id, lat, log
# because this had the higher count from the initial dataset, going with end_station_id
end_station_info <- citibike %>%
  dplyr::select(end.station.id, end.lng, end.lat)

end_station_info <- end_station_info[!duplicated(end_station_info$end.station.id),]

# Now I want the coordinates of all those station_ids
station_surplus_count_coords <- merge(x = station_surplus_count, y = end_station_info, by.x = 'station.id',
  by.y = 'station.id')

colnames(station_surplus_count_coords)[3] <- "lng"
colnames(station_surplus_count_coords)[4] <- "lat"

station_surplus_count_coords <- station_surplus_count_coords %>%
  add_row(station.id = "ABAN", surplus.sum=1363, lng=-73.99, lat=40.67)

# Using basemaps for NYC
m <- leaflet(data=station_surplus_count_coords) %>%
  # setView(zoom=12) %>%
  addTiles() %>%
  addCircleMarkers(
    ~lng, ~lat,
    popup=~as.character(station.id),
    label=~as.character(station.id),
    radius=.5,
    color = ~ifelse(surplus.sum >= 1, 'blue',
                    ifelse(surplus.sum == 0, 'green', 'red'))
  )

# Display map
#m
par(mar = c(0.1, 4.1, 1.1, 4.1))
img <- readJPEG("stations_surplus_sum.jpg")
plot(1:10, ty="n", axes = 0, xlab='', ylab='', asp=1.0)
p_title <- 'Overall Surplus/Shortage by Docking Station'
p_subtitle <- "Surplus: Blue -- Shortage: Red -- Even: Green"
title(side = 3, line=-1, adj=0, p_title)
mtext(side = 3, line=-3, adj=0, p_subtitle)
rasterImage(img,-1,0,12,10)

```

```

stations_with_elevation <- read.csv('stations_with_elevation.csv', row.names = 1, header= TRUE)

stations_with_boro_hood <- read.csv('stations_with_boro_and_hood.csv', row.names = 1, header= TRUE)

# Combine the elevation, borough, neighborhood, and September surplus
# First let's trim the DF for elevation
stations_with_elevation_trim <- stations_with_elevation %>%
  dplyr::select(short_name, station_id, elevation, elev_units)

stations_with_boro_hood_trim <- stations_with_boro_hood %>%
  dplyr::select(short_name, name, station_id, capacity, ntaname, boro_name, lon, lat)

stations_attrs_trim <-
  merge(stations_with_elevation_trim,
        stations_with_boro_hood_trim,
        by.x=c('short_name'),
        by.y=c('short_name'), all = TRUE)

stations_attrs_trim <- stations_attrs_trim %>%
  dplyr::select(-station_id.y)

colnames(stations_attrs_trim)[colnames(stations_attrs_trim) == 'station_id.x'] <- 'station_id'

stations_attrs_trim[c("boro_name")][is.na(stations_attrs_trim[c("boro_name"))])] <- "New Jersey"

stations_attrs_trim <-
  stations_attrs_trim %>%
  mutate(ntaname = ifelse(startsWith(short_name, "JC"), "Jersey City", ntaname))

stations_attrs_trim <-
  stations_attrs_trim %>%
  mutate(ntaname = ifelse(startsWith(short_name, "HB"), "Hoboken", ntaname))

stations_attrs_trim_sur <-
  merge(stations_attrs_trim,
        station_surplus_count,
        by.x=c('short_name'),
        by.y=c('station.id'), all.x = TRUE)

stations_attrs_trim_sur <- stations_attrs_trim_sur %>%
  filter(!is.na(surplus.sum))

stations_attrs_trim_sur %>%
  filter(surplus.sum >= -100 & surplus.sum <= 100 & boro_name %in% c('Bronx', 'Brooklyn', 'Manhattan',
  ggplot(aes(x=surplus.sum, color=boro_name), ) +
  theme(legend.position="bottom") +
  geom_histogram(bins=201) +
  facet_wrap(~boro_name) +
  labs(x = 'Surplus Count',
       y = 'Number of Stations',
       title = "Station Surplus by Borough",
       fill = "Borough",

```

```

        color='Borough') +
  theme(legend.position="none")
citibike_bike_avail <- fread("bike_avail_by_station_and_time.csv", data.table=FALSE, check.names=FALSE)

citibike_bike_avail <- citibike_bike_avail %>%
  dplyr::select(-V1)

citibike_bike_avail_long <- citibike_bike_avail %>%
  pivot_longer(!timestamp, names_to = "station.id", values_to = "bikes.avail")

citibike_bike_avail_long_trim <- citibike_bike_avail_long %>%
# filter(as.integer(station.id) == 3582 & endsWith(as.character(timestamp), "00:00"))
filter(as.integer(station.id) == 3582)

p_rebalance_station <- ggplot(citibike_bike_avail_long_trim,
                               aes(x=timestamp, y=bikes.avail, group=station.id)) +
  geom_line(aes(color=station.id), show.legend = FALSE) +
#  geom_point(aes(color=station.id), show.legend = FALSE) +
  labs(x='Time',
       y='Available Bikes',
       title="Docking Station 3582")

p_rebalance_station
# Read in the csv of the API responses which have been wrangled together
stations_with_bike_avail <- read.csv('bike_avail_by_station_and_time.csv', row.names = 1, header= TRUE)

stations_with_bike_avail_long <- stations_with_bike_avail %>%
  pivot_longer(!timestamp, names_to = "station.id", values_to = "bikes.avail.count")

stations_with_elevation <- read.csv('stations_with_elevation.csv', row.names = 1, header= TRUE)

stations_with_boro_hood <- read.csv('stations_with_boro_and_hood.csv', row.names = 1, header= TRUE)

# Combine the elevation, borough, neighborhood, and September surplus
# First let's trim the DF for elevation
stations_with_elevation_trim <- stations_with_elevation %>%
  dplyr::select(short_name, station_id, elevation, elev_units)

stations_with_boro_hood_trim <- stations_with_boro_hood %>%
  dplyr::select(short_name, name, station_id, capacity, ntaname, boro_name, lon, lat)

stations_attrs_trim <-
  merge(stations_with_elevation_trim,
        stations_with_boro_hood_trim,
        by.x=c('short_name'),
        by.y=c('short_name'), all = TRUE)

stations_attrs_trim <- stations_attrs_trim %>%
  dplyr::select(-station_id.y)

colnames(stations_attrs_trim)[colnames(stations_attrs_trim) == 'station_id.x'] <- 'station_id'

stations_attrs_trim[c("boro_name")][is.na(stations_attrs_trim[c("boro_name"))])] <- "New Jersey"

```

```

stations_attrs_trim <-
  stations_attrs_trim %>%
  mutate(ntaname = ifelse(startsWith(short_name, "JC"), "Jersey City", ntaname))

stations_attrs_trim <-
  stations_attrs_trim %>%
  mutate(ntaname = ifelse(startsWith(short_name, "HB"), "Hoboken", ntaname))

stations_attrs_trim <- stations_attrs_trim %>%
  rename(short.name=short_name, station.id=station_id, elev.units=elev_units, nta.name=ntaname, boro.name=boro.name)

stations_attrs_trim_bk <- stations_attrs_trim %>%
  filter(boro.name == "Brooklyn")

# Distance matrix for docking stations
# Result is in meters
dist_mat <- distm(stations_attrs_trim_bk[9:10], stations_attrs_trim_bk[9:10], fun=distHaversine)
dist_mat <- as.data.frame(dist_mat)

dist_mat[is.na(dist_mat)] <- 0
dMat <- as.dist(dist_mat)

# Now for the clustering
hier_clust <- hclust(dMat, method = "complete")
# 400 meters is about a quarter of a mile (0.248548 miles)
stations_attrs_trim_bk$cluster <- cutree(hier_clust, h=400)

station_to_cluster <- stations_attrs_trim_bk %>%
  dplyr::select(station.id, cluster, elevation, capacity)

# Merge long df with counts with station.id and cluster to label clusters properly
stations_bike_avail_by_time <-
  merge(stations_with_bike_avail_long,
        station_to_cluster,
        by.x=c('station.id'),
        by.y=c('station.id'), all.x = TRUE)

stations_bike_avail_by_time_no_na <- stations_bike_avail_by_time %>%
  filter(!is.na(cluster))

stations_bike_avail_by_time_no_na_group_sum <- stations_bike_avail_by_time_no_na %>%
  group_by(timestamp, cluster) %>%
  summarise_at(vars(bikes.avail.count), sum)

stations_bike_avail_by_time_no_na_group_mean <- stations_bike_avail_by_time_no_na %>%
  group_by(timestamp, cluster) %>%
  summarise_at(vars(elevation), mean)

stations_bike_avail_by_time_no_na_group <- cbind(stations_bike_avail_by_time_no_na_group_sum, stations_bike_avail_by_time_no_na_group_mean)

# mutate to convert timestamp into day of the week, etc.
stations_bike_avail_by_time_no_na_group <- stations_bike_avail_by_time_no_na_group %>%
  mutate(time=as.ITime(ymd_hms(timestamp)),

```

```

weekday = lubridate::wday(timestamp, label=TRUE, abbr=TRUE))

stations_bike_avail_by_time_no_na_group$cluster <- as.factor(stations_bike_avail_by_time_no_na_group$cluster)
stations_bike_avail_by_time_no_na_group$time <- as.factor(stations_bike_avail_by_time_no_na_group$time)
stations_bike_avail_by_time_no_na_group$weekday <- factor(stations_bike_avail_by_time_no_na_group$weekday)

stations_bike_avail_by_time_no_timestamp <- subset(stations_bike_avail_by_time_no_na_group, select=-c(timestamp))

stations_bike_avail_by_time_1H <- stations_bike_avail_by_time_no_timestamp %>%
  filter(endsWith(as.character(time), "00:00"))

stations_bike_avail_by_time_1H <- stations_bike_avail_by_time_1H %>%
  mutate(day = ifelse(weekday %in% c('Sat', 'Sun'), 'WKND', 'WDAY'))

# Table of availability based on 1HR intervals
tab_1H <- table(stations_bike_avail_by_time_1H$bikes.avail.count)

# This plot shows the available bike count frequencies given 1HR intervals and Brooklyn station cluster
# There appears to be a max around 22 or so as the distribution drops off just before 25, likely a result of
# rounding or a limit in the data
tab_1H_df <- as.data.frame(tab_1H)

tab_1H_df$Var1 <- as.integer(tab_1H_df$Var1)

# Distribution of count results
p_distro_avail_counts <- tab_1H_df %>%
  filter(Var1 < 250) %>%
  ggplot(aes(x=Var1, y=Freq)) +
  geom_bar(stat="identity") +
  labs(x='Availability Count',
       y='Frequency',
       title='Frequency of Hourly Available Bike Counts for Brooklyn Clusters')

# Display plot
p_distro_avail_counts
stations_bike_avail_by_time_1H_imp <- stations_bike_avail_by_time_1H

# 71568 rows total in the train set
# 2992 in which the bikes.avail.count greater than capacity
# 125 clusters have avail greater than capacity

# Impute the available bike count to match the capacity
stations_bike_avail_by_time_1H_imp$bikes.avail.count <- ifelse(stations_bike_avail_by_time_1H_imp$bikes.avail.count > stations_bike_avail_by_time_1H_imp$capacity,
                                                               stations_bike_avail_by_time_1H_imp$capacity,
                                                               stations_bike_avail_by_time_1H_imp$capacity,
                                                               stations_bike_avail_by_time_1H_imp$bikes.avail.count)

#stations_bike_avail_by_time_1H <- stations_bike_avail_by_time_no_timestamp %>%
#  filter(endsWith(as.character(time), "00:00"))

# Start with data partition here.

```

```

set.seed(8675309)
index <- sample(2, nrow(stations_bike_avail_by_time_1H_imp), replace = TRUE, p=c(0.75, 0.25))
#index <- sample(2, nrow(stations_bike_avail_by_time_1H), replace = TRUE, p=c(0.75, 0.25))
train_1H <- stations_bike_avail_by_time_1H_imp[index==1,]
test_1H <- stations_bike_avail_by_time_1H_imp[index==2,]

# Sample Variance is 313
#var(stations_bike_avail_by_time_1H$bikes.avail.count)
n <- length(stations_bike_avail_by_time_1H_imp)
# Population variance
#var(stations_bike_avail_by_time_1H$bikes.avail.count)*(n-1)/n
# Mean is 13
#mean(stations_bike_avail_by_time_1H$bikes.avail.count)

# Over dispersion exists
# POISSON
mod_1H_pois <- glm(bikes.avail.count ~ cluster + time + day, data = train_1H, family = "poisson")
mod_1H_pois_sum <- summary(mod_1H_pois)

# Taking the floor as that is the actual available bikes, no partial bikes
pred_1H_pois <- predict.glm(mod_1H_pois, newdata = test_1H, type = "response")
rmse_mod_1H_pois <- ModelMetrics::rmse(test_1H$bikes.avail.count,floor(pred_1H_pois))
mae_mod_1H_pois <- mae(test_1H$bikes.avail.count,floor(pred_1H_pois))
mase_mod_1H_pois <- mase(test_1H$bikes.avail.count, floor(pred_1H_pois))
mod_1H_pois_dev <- mod_1H_pois_sum$deviance
mod_1H_pois_df <- mod_1H_pois_sum$df[2]
mod_1H_pois_aic <- mod_1H_pois_sum$aic
p_resid_pois <- ggplot(mod_1H_pois, aes(x = .fitted, y = .resid)) +
  geom_point() +
  geom_hline(yintercept = 0) +
  labs(title='Poisson', x='Fitted Values', y='Residuals')

p_resid_pois <- p_resid_pois + xlim(-5, 10)
disp_test <- dispersiontest(mod_1H_pois)
# This indicates dispersion
disp_val <- as.numeric(disp_test$estimate[1])
# QUASI-POISSON
mod_1H_qp <- glm(bikes.avail.count ~ cluster + time + day, data = train_1H, family = "quasipoisson")
mod_1H_qp_sum <- summary(mod_1H_qp)

pred_1H_qp <- predict.glm(mod_1H_qp, newdata=test_1H, type = "response")
rmse_mod_1H_qp <- ModelMetrics::rmse(test_1H$bikes.avail.count,floor(pred_1H_qp))
mae_mod_1H_qp <- mae(test_1H$bikes.avail.count,floor(pred_1H_qp))
mase_mod_1H_qp <- mase(test_1H$bikes.avail.count, floor(pred_1H_qp))
p_resid_qp <- ggplot(mod_1H_qp, aes(x = .fitted, y = .resid)) +
  geom_point() +
  geom_hline(yintercept = 0) +
  labs(title='Quasi-Poisson', x='Fitted Values', y='Residuals')

p_resid_qp <- p_resid_qp + xlim(-5, 10)
mod_1H_qp_dev <- mod_1H_qp_sum$deviance
mod_1H_qp_df <- mod_1H_qp_sum$df[2]
mod_1H_qp_aic <- mod_1H_qp_sum$aic

```

```

# NEGATIVE BINOMIAL
mod_1H_nb <- glm.nb(bikes.avail.count ~ cluster + time + day, data=train_1H)
mod_1H_nb_sum <- summary(mod_1H_nb)

pred_1H_nb <- predict.glm(mod_1H_nb, newdata=test_1H, type = "response")
rmse_mod_1H_nb <- ModelMetrics::rmse(test_1H$bikes.avail.count,floor(pred_1H_nb))
mae_mod_1H_nb <- mae(test_1H$bikes.avail.count,floor(pred_1H_nb))
mase_mod_1H_nb <- mase(test_1H$bikes.avail.count, floor(pred_1H_nb))
mod_1H_nb_dev <- mod_1H_nb$deviance
#mod_1H_nb_df <- mod_1H_nb$df[2]
mod_1H_nb_aic <- mod_1H_nb$aic
p_resid_nb <- ggplot(mod_1H_nb, aes(x = .fitted, y = .resid)) +
  geom_point() +
  geom_hline(yintercept = 0) +
  labs(title='Negative Binomial', x='Fitted Values', y='Residuals')

p_resid_nb <- p_resid_nb + xlim(-5, 10)
deviances <- c(mod_1H_pois_dev, mod_1H_qp_dev, mod_1H_nb_dev)
degfrees <- c(mod_1H_pois_df, mod_1H_qp_df, "NA")
aics <- c(mod_1H_pois_aic, mod_1H_qp_aic, mod_1H_nb_aic)

models_stats <- c("Poisson","Quasi-Poisson","Negative Binomial")

data.frame(Model=models_stats, Deviance=deviances, Degrees.Freedom=degfrees, AIC=aics) %>%
  kable(digits = 1) %>%
  kable_paper("hover", full_width = F) %>%
  kable_styling(latex_options = "HOLD_position")
plot_grid(p_resid_pois, p_resid_qp, p_resid_nb)
# ZERO INFLATED: POISSON
mod_1H_zero_pois <- zeroinfl(bikes.avail.count ~ cluster + time + day, data=train_1H, dist = "poisson")
mod_1H_zerop_sum <- summary(mod_1H_zero_pois)

pred_1H_zero_pois <- predict(mod_1H_zero_pois, newdata=test_1H,type = "response")
rmse_mod_1H_zero_pois <- ModelMetrics::rmse(test_1H$bikes.avail.count,floor(pred_1H_zero_pois))
mae_mod_1H_zero_pois <- mae(test_1H$bikes.avail.count,floor(pred_1H_zero_pois))
mase_mod_1H_zero_pois <- mase(test_1H$bikes.avail.count, floor(pred_1H_zero_pois))
# ZERO INFLATED: NEGATIVE BINOMIAL
mod_1H_zero_nb <- zeroinfl(bikes.avail.count ~ cluster + time + day, data=train_1H,dist = "negbin")
#summary(mod_1H_zero_nb)

pred_1H_zero_nb <- predict(mod_1H_zero_nb, newdata=test_1H ,type = "response")
rmse_mod_1H_zero_nb <- ModelMetrics::rmse(test_1H$bikes.avail.count,floor(pred_1H_zero_nb))
mae_mod_1H_zero_nb <- mae(test_1H$bikes.avail.count,floor(pred_1H_zero_nb))
mase_mod_1H_zero_nb <- mase(test_1H$bikes.avail.count, floor(pred_1H_zero_nb))
rmse_1H <- c(rmse_mod_1H_pois, rmse_mod_1H_qp, rmse_mod_1H_nb,
              rmse_mod_1H_zero_pois, rmse_mod_1H_zero_nb)

# Calculate normalized RMSE with 237 as the max bike avail count for test data
rmse_1H_norm <- rmse_1H/237

mae_1H <- c(mae_mod_1H_pois, mae_mod_1H_qp, mae_mod_1H_nb,
             mae_mod_1H_zero_pois, mae_mod_1H_zero_nb)

```

```

mase_1H <- c(mase_mod_1H_pois, mase_mod_1H_qp, mase_mod_1H_nb,
              mase_mod_1H_zero_pois, mase_mod_1H_zero_nb)

aic_1H <- c(mod_1H_pois$aic, mod_1H_qp$aic, mod_1H_nb$aic,
              mod_1H_zero_pois$loglik, mod_1H_zero_nb$loglik)

pred_zero_1H <- c("163", "163", "163", "133", "133")

models_1H <- c("Poisson",
                 "Quasi-Poisson",
                 "Negative Binomial",
                 "Zero-Infl. (Poisson)",
                 "Zero-Infl. (NB)")

#data.frame(models_1H, rmse_1H, mae_1H) %>%
#  arrange(rmse_1H)
df_for_plot <- as.data.frame(cbind(test_1H,
                                      floor(pred_1H_pois),
                                      floor(pred_1H_qp),
                                      floor(pred_1H_nb),
                                      floor(pred_1H_zero_pois),
                                      floor(pred_1H_zero_nb))) %>%
  rename(Actual='bikes.avail.count', Pois.Prediction=8, QPois.Prediction=9,
         NB.Prediction=10, Zero.Pois.Prediction=11, Zero.NB.Prediction=12)

df_for_plot$Actual <- as.integer(df_for_plot$Actual)
df_for_plot$Pois.Prediction <- as.integer(df_for_plot$Pois.Prediction)
df_for_plot$QPois.Prediction <- as.integer(df_for_plot$QPois.Prediction)
df_for_plot$NB.Prediction <- as.integer(df_for_plot$NB.Prediction)
df_for_plot$Zero.Pois.Prediction <- as.integer(df_for_plot$Zero.Pois.Prediction)
df_for_plot$Zero.NB.Prediction <- as.integer(df_for_plot$Zero.NB.Prediction)

miss_zero_pois <- df_for_plot %>%
  filter(Pois.Prediction > 0 & Actual == 0) %>%
  count()
miss_zero_qp <- df_for_plot %>%
  filter(QPois.Prediction > 0 & Actual == 0) %>%
  count()
miss_zero_nb <- df_for_plot %>%
  filter(NB.Prediction > 0 & Actual == 0) %>%
  count()
miss_zero_z_p <- df_for_plot %>%
  filter(Zero.Pois.Prediction > 0 & Actual == 0) %>%
  count()
miss_zero_z_nb <- df_for_plot %>%
  filter(Zero.NB.Prediction > 0 & Actual == 0) %>%
  count()

miss_zero_1H <- c(miss_zero_pois[1,1], miss_zero_qp[1,1], miss_zero_nb[1,1],
                    miss_zero_z_p[1,1], miss_zero_z_nb[1,1])
data.frame(Model=models_1H, RMSE=rmse_1H, MAE=mae_1H, MASE=mase_1H, Missed.Zero=miss_zero_1H) %>%
  arrange(rmse_1H) %>% kable(digits = 4) %>%
  kable_paper("hover", full_width = F) %>%

```

```

kable_styling(latex_options = "HOLD_position")
# Modify the number of rows to consider
# 17715 rows in DF
df_for_plot_trim <- df_for_plot[500:600,]

p_pred_vs_actual <- ggplot() +
  geom_line(data = df_for_plot_trim, aes(x = 1:nrow(df_for_plot_trim), y = Pois.Prediction, color="Predictions")) +
  geom_line(data = df_for_plot_trim, aes(x = 1:nrow(df_for_plot_trim), y = Actual, color = "Actuals")) +
  labs(x='Sample Index',
       y='Available Bike Count',
       title='Availability Counts and Predictions') +
  scale_color_manual(values = c("Predictions" = "blue", "Actuals" = "red")) +
  theme(legend.position="bottom",
        legend.title=element_blank())

p_pred_vs_actual
# Distribution of count predictions
p_distro_avail_count_preds <- df_for_plot %>%
  ggplot(aes(x=Pois.Prediction)) +
  geom_histogram(binwidth=1) +
  labs(x='Availability Count',
       y='Frequency',
       title='Frequency of Hourly Available Bike Count Predictions')

# Display plot
p_distro_avail_count_preds
predict_num_bikes_avail <- function(longitude, latitude, time, day) {}
predict_num_bikes_avail <- function(longitude, latitude, time, day) {
  #longitude: -73.960859 (in Brooklyn within quarter mile of docking station)
  #latitude: 40.67355 (in Brooklyn within quarter mile of docking station)
  #time: "00:00:00"/"01:00:00"/"02:00:00"/"03:00:00"/"04:00:00"/"05:00:00"/
  #      "06:00:00"/"07:00:00"/"08:00:00"/"09:00:00"/"10:00:00"/"11:00:00"/
  #      "12:00:00"/"13:00:00"/"14:00:00"/"15:00:00"/"16:00:00"/"17:00:00"/
  #      "18:00:00"/"19:00:00"/"20:00:00"/"21:00:00"/"22:00:00"/"23:00:00"/
  #day: "WKND"/"WDAY"

  # Convert lon/lat to cluster
  location <- data.frame(matrix(nrow = 1,data = c(longitude, latitude)))
  closest_station <- nn2(stationsAttrsTrimBk[, 9:10], query=location, k=1)
  inp_cluster <- stationsAttrsTrimBk[closest_station$nn.idx,]$cluster

  #print(inp_cluster)

  # Create input for prediction
  bike_avail_query <- data.frame(matrix(nrow = 1, data = c(inp_cluster, 0, time, day)))
  colnames(bike_avail_query) <- c("cluster", "bikes.avail.count", "time", "day")

  # Predict using Model: mod1
  num_bikes_avail <- predict.glm(mod_1H_pois, newdata = bike_avail_query, type = "response")
  # Take floor of prediction to ensure whole number
  num_bikes_avail <- as.integer(floor(num_bikes_avail))

  return(c(num_bikes_avail, inp_cluster))
}

```

```

}

# Crown Heights
prediction_CH <- predict_num_bikes_avail(-73.960859, 40.67355,
                                         "22:00:00", "WDAY")

#print(paste0("Crown Heights - Available Bikes: ", prediction_CH[1], "; Cluster: ", prediction_CH[2]))
# Williamsburg
prediction02_WB <- predict_num_bikes_avail(-73.9617, 40.7192,
                                             "18:00:00", "WKND")

#print(paste0("Williamsburg - Available Bikes: ", prediction02_WB[1], "; Cluster: ", prediction02_WB[2]))
# Sunset Park
prediction02_SP <- predict_num_bikes_avail(-74.00509, 40.64338,
                                             "17:00:00", "WDAY")

#print(paste0("Sunset Park - Available Bikes: ", prediction02_SP[1], "; Cluster: ", prediction02_SP[2]))
hoods <- c("Crown Heights", "Williamsburg", "Sunset Park")
lons <- c(-73.960859, -73.9617, -74.00509)
lats <- c(40.67355, 40.7192, 40.64338)
times <- c("22:00:00", "18:00:00", "17:00:00")
days <- c("WDAY", "WKND", "WDAY")
preds <- c(prediction_CH[1], prediction02_WB[1], prediction02_SP[1])
clusts <- c(prediction_CH[2], prediction02_WB[2], prediction02_SP[2])

data.frame(Neighborhood=hoods, Longitude=lons, Latitude=lats, Time=times, Day=days, Prediction=preds, Cluster=clusts) %>%
  kable_paper("hover", full_width = F) %>%
  kable_styling(latex_options = "HOLD_position")
# https://yihui.org/en/2018/09/code-appendix/

```