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2023
CMMC
Summary Sheet

The "Big Green Apple" proposal

Summary

New York City, with its ever growing population, has become a global center in multiple senses in the world, yet with its old city planning and outdated infrastructure, needs a fresh breeze of air for change. One way is by expanding the current transportation system. New York City has made a name for itself due to its expansive bus and subway system, but a new found desire for healthier lifestyles and the quest for accessibility made biking another popular option. The goal of this report is to shed light on the blind spots the current biking system failed to consider and give some recommendations on how it can be improved. We are expected to provide some options for policy makers so they could implement changes to make the biking experience in New York better. To meet that goal, we established two models: Model I: Biking Population Growth in Queens and Model II: Logistical Growth Model with the entropy weight method.

For Model I, this report examined why we chose Queens as a point of interest to study, due to its overall spiked projected biker population growth rate despite its stable general population growth rate compared to the other New York City boroughs. Based on our analysis, we then did two predictions under ideal conditions that only vary in priorities using a gravity model. One prioritizes dense areas while the other focuses on historically underserved communities in Queens, both being indicators of high demand. Using this model, we were able to see a difference in the projected ridership number in Queens in absolute terms within these two parameters.

For Model II, this report defined the coefficients that actively affect functions in our logistic growth model, and using the Entropy Weight Method(EWM), we were able to effectively eliminate the differences across various coefficient dimensions. We established a Logistical Growth Model to optimize injury rates under the given 7.25 million dollars of federal grant. We defined some strengths protected bike lanes had over conventional ones, and then, we did a case study with common shapes of intersections that have a higher injury rate due to its denser traffic and see how protected bike lanes can help further reduce injury rates, with some even doubling the effect, from -45% to -110%.

Additionally, this report discussed the benefits of utilizing such a way to analyze the effectiveness of installing new bike lanes, bringing other types of traffic into the bigger picture. We determined that although constructing protected bike lanes might bring additional traffic to the normal engined vehicles, it also hence encourages residents in these areas to choose biking over the more traditional public transportation while doing what they can for the environment. We can say with confidence that with our models and evaluations, a policy maker can therefore make more informed decisions and get a bigger picture of the entire biking infrastructure in New York, and thus promote safe biking for all.

Keywords: alternative transportation, logarithmic model, entropy weight method, promote safe biking

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1 Introduction

1.1 Problem Background

With the ever expanding population of New York City, there has also been an increasing demand for transportation around the greater New York area. Living or working in one of the biggest cultural and economical centers in the world, the modern New Yorkers have to think beyond the existing bus and train system and consider new ways of getting around New York City. A large population is looking to biking as an alternative solution to traveling in a more environmentally friendly way and avoid the traffic congestion that has been plaguing the urban area. Furthermore, the popularity of cycling races like GFNY world championships NYC has encouraged residents of New York to consider biking in addition to other public transportation options. The advancements in technology also made bike sharing a possibility, hence offering the choice to bike when one does not own a bike. Since there has been an increase in the population who chose bike riding in recent years, additional concerns such as accessibility and road management need to be addressed. However, due to the history of the city and its limitations, a better infrastructure is needed to promote safe and efficient cycling for all.

(a)Bikers in NYC[1] (b)Citi bike, a bike sharing platform[3]

Figure 1: biking in NYC overview

Challenged by the CMMC, we built a model to generate a strategy to improve and expand the existing cycling infrastructure in New York City.

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems:

- Identify one area in New York City where there exists a demand for a better biking infrastructure, compare the socio-economic impact when prioritizing historically underserved and low income populations with a need for accessible transportation to work versus prioritizing areas of high density in general;
- Evaluate the benefits of various kinds of bike lanes and build a mathematical model to optimize the best mix of them in order to encourage the less represented to start biking

more with the given monetary constraint;
- Show how your strategy is the best available choice and evaluate the impacts of the proposal;
- Determine how well the model operates in a larger sense considering the benefits and weaknesses with the normal city traffic;
- Present the strategies, model justifications and possible policies to the Commissioner of the Department of Transportation(DOT).

1.3 Our Work

The topic requires us to improve the pre-existing biking framework in New York, and discuss potential strategies when prioritizing certain communities and types of bike lanes within our given budget. Our work mainly includes the following:
- We identify the area that has the most demand for bike lanes and use a model to evaluate the social impact in terms of increase of biking population when putting emphasis on two different parameters;
- We establish another model to compare benefits of protected bike lanes versus conventional bike lanes and assess the impact in terms of injury rates, thus optimizing the construction of bike lanes utilizing the funds given;
- We take the constraints such as other engine powered vehicle traffic into account and analyze the effects of building these bike lanes in terms of general traffic growth .

Firstly, identify a region that deserves our attention by assigning a score to each of the boroughs in New York City based on income, projected biking population and percentage of area unplanned(i.e. Currently no bike lanes). Then, highlighting areas of high density and historically underserved communities, we can calculate how much social impact we made by looking at the projected biking population trend. We can hence turn our attention to putting together a plan that we can generalize to the entire New York City by doing a cost/gain analysis when constructing conventional and protected bike lanes, thus determining the best mix of both to promote healthy change in the demographics of New York bikers. Lastly, we assess the chain effect caused by the plan and do a full evaluation of our tactics within a bigger picture.

In summary, the entire modeling process can be shown as follows:

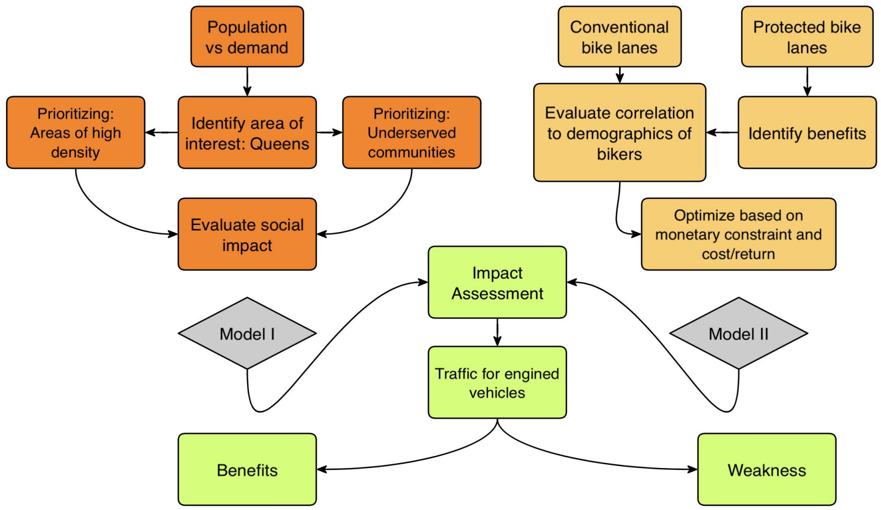


Figure 2: Model Overview

2 Assumptions and Justifications

To simplify the problem, we make the following basic assumptions, each of which is properly justified.

- **We assume the bus and subway system in New York will be relatively fixed.**
  - **Justification:** MTA has been making changes and adding new lines to the existing subway and bus system in recent years, and even though more of such is appreciated, there will not be any significant changes in the near future.
- **We assume that Staten Island is not worth considering.**
  - **Justification:** The demand for bike lanes on Staten Island is rather low compared to the other major boroughs of New York since it is mostly residential rather than both residential and commercial.
- **Assume that the money will only be used for constructions of bike lanes and the cost is an educated estimation.**
  - **Justification:** Although there are many more factors that might be considered when one chooses biking as a mode of transportation such as the ease of navigation and the possibility of bikes getting stolen, we won't consider them since funds are limited. We will also estimate and use the upper bound when it comes to evaluating costs of construction and maintenance.
- **Assume that the effectiveness of bike lanes across boroughs are similar.**
  - **Justification:** Though the traffic situation in different boroughs are relatively different, for the ease of calculation and generalization we will assume that those factors don't make a large difference when choosing types of bike lanes to install.

3 Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1: Notations used in this paper

Symbol	Definition
$N(A)$	Net value of a bike lane project in area A
$S(A)$	Initial State without any construction in area A
$C(A)$	Total cost of constructing bike lanes in area A
$I(A)$	Implemental score of area A
$E(A)$	External Costs of constructing bike lanes in area A
m	Maximum rate of impact for unit bike lane on I
k	Maximum impact that has the potential to be changed
x_i	Indicators for different parameters that affect m and k

4 Model I: Biking Population growth in Queens

4.1 Identifying area of interest: Selection of borough

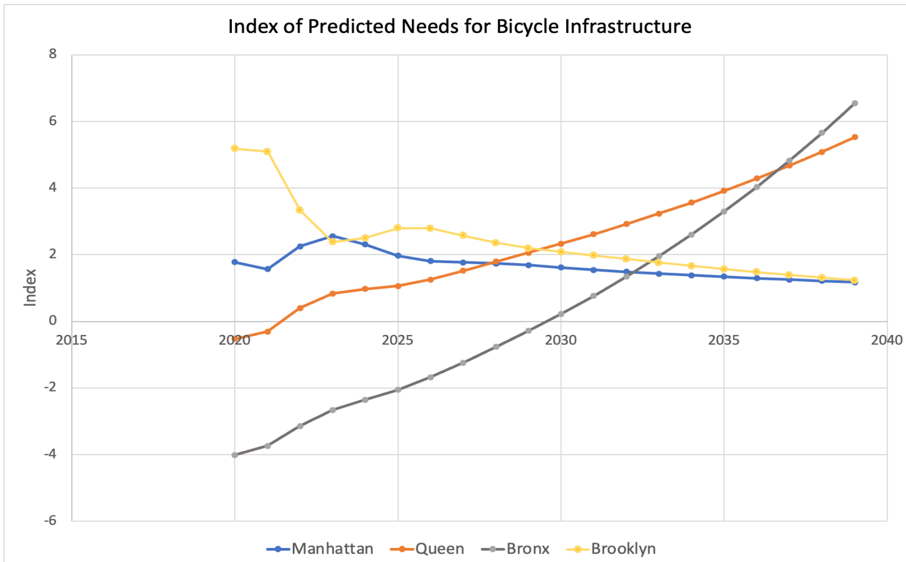
We are only allowed to choose one borough out of the four boroughs of New York City to focus on and maximize the social impact there, so we decided on Queens since we think there is a higher demand for bike lanes there. We reached this conclusion from the analysis below:

By looking at the data of ridership versus general population breakdown in each of the boroughs, while population breakdown remains stable throughout the years, we observed the greatest rate of growth of ridership in Queens.

Number of riders by borough			Borough population as a proportion of the total population		
	2001	2021	2001	2020	2040
Manhattan	6k	21k	16.64%	16.92%	17.5%
Queens	2k	9k	19.2%	19.16%	18.74%
Bronx	0.8k	2.7k	27.84%	27.25%	26.73%
Brooklyn	8k	23k	30.78%	30.97%	31.47%

Figure 3: Ridership number vs population breakdown in each borough

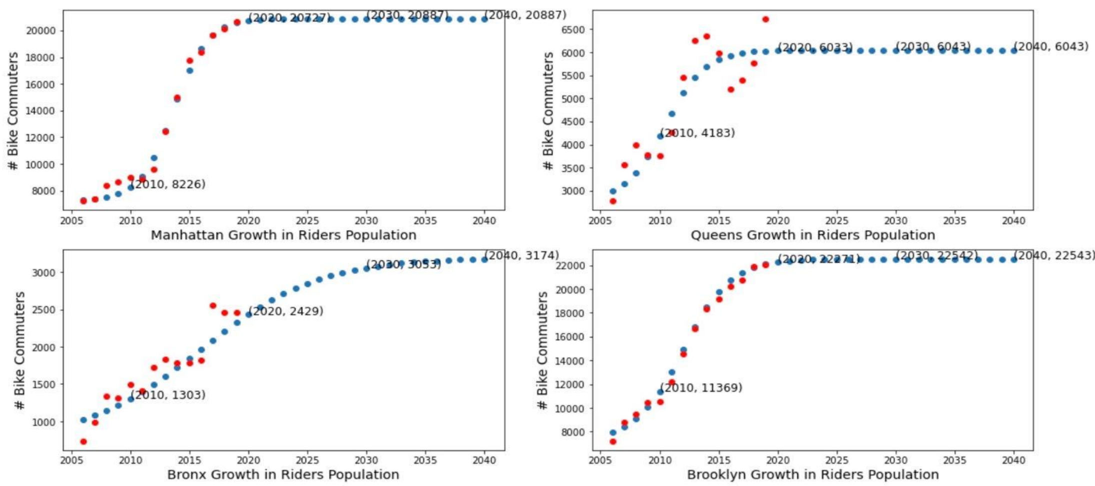
To confirm our intuition, we assigned each borough a score to indicate which has the highest priority based on the factors demanded by the CMMC. We used the median income of the households in New York City for our first parameter. Secondly, the projected biking population is a concern of ours because it indicates the location where there will be the most demand for bike lanes in general. Another factor is a score for the population density. And lastly, we need to consider the number of subway and bus stops within the entire boroughs. The index is calculated by using constants which would project all the boroughs within the range of [-10,10]. Taking all four factors into count, we predicted the priority scores of the four boroughs in the near future.



The Index is calculated by $Index_n = \alpha * \frac{i_{NYC}}{i_n} + \beta * \frac{P}{d} - \gamma_1 * S - \gamma_2 * B$,

Where i_{NYC} *and* i_n represent average of median income of New York City and that of borough i, respectively, P predicts growth of ridership population based on non-parametric model. We attempted two models for P, the logistic regression and the non-parametric regression via Bayes modeling, and we used the latter because the carrying capacity predicted by the logistic regression inherently assumes some level of saturation of the existing biking infrastructure. D indicates the population density; S and B represent the availability of subway and bus routes, respectively. As seen from the graph, we see a growth of priority score in Queens, thus we decided to use Queens as a snapshot to analyze. Please check the graph below for details regarding our prediction model of the projected ridership growth across boroughs.

A)



B)

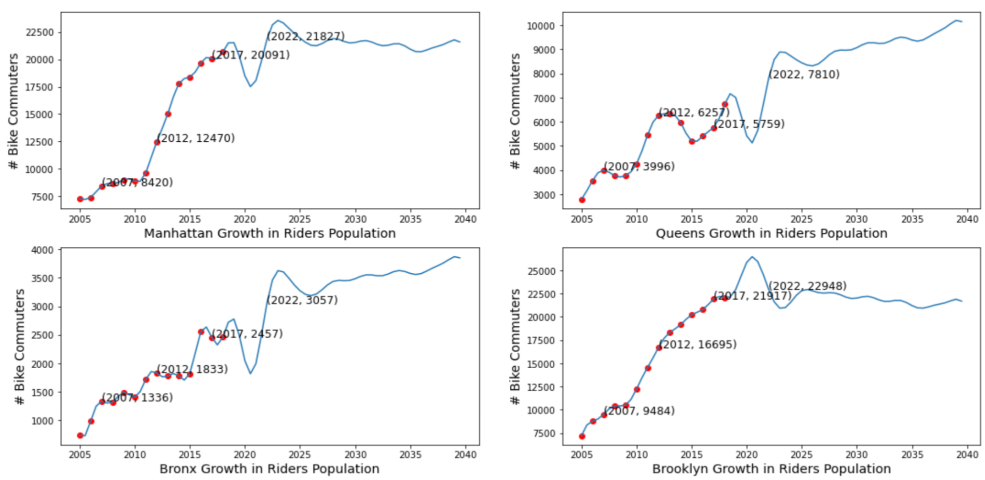


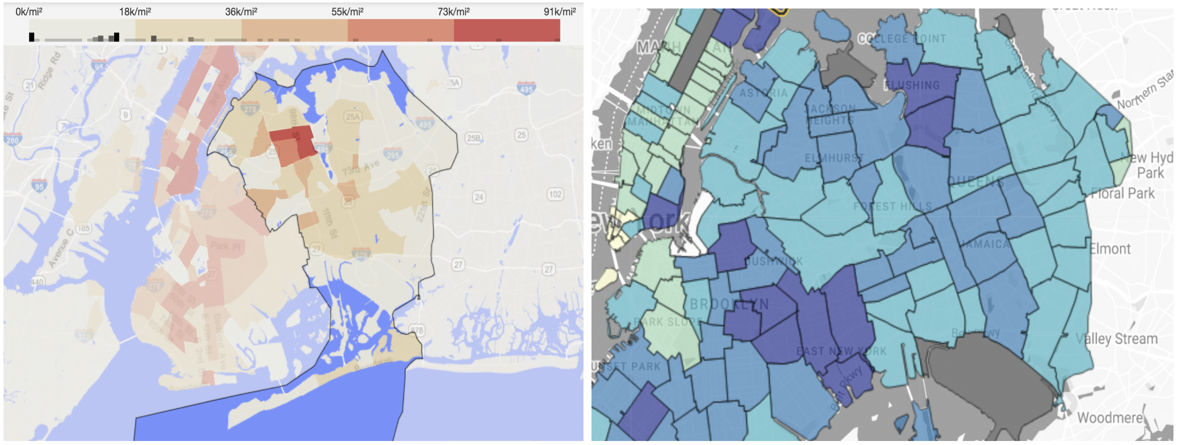
Figure 4: Growth prediction in each borough Using A)Logistic Regression and B)Nonparametric Bayesian Model

4.2 Comparative effect analysis for different priorities

As we mentioned before, we will be measuring socio-economic impact by comparing the predicted rider amount in Queens when prioritizing areas of high density or areas of residence for underserved communities.

First, we took a look at the population density in Queens from the map and identified areas of interest. From the map, we found that the highest density of population is concentrated in the Corona-Jackson Heights Area, with Corona having a population density of 80,744/$mile^2$ and Jackson Heights with a population density of 90,929/$mile^2$. Even though income level isn't the sole indicator for where historically underserved communities reside, there is still a strong correlation, therefore we will use it as a determining factor.

According to the map, the lowest median income is concentrated in the Flushing area, with a median household income of $40,786/year.



(a)Population density[4] (b)Income median, lighter color corresponding to higher income[5]

Figure 5: Queens population density and income median by color

To best predict the number of bikers that will use these newly constructed bike lanes in each situation, we cannot disregard the already existing bike lanes in these areas as well as the current population. According to the New York Open Data set[2], Corona and Jackson Heights have a combined population of 165,810 and Flushing has a population of 72,008. As for the number of bike lanes, Downtown Flushing has about an estimate of 12 miles of bike lanes, while Corona and Jackson Heights have a combined length of around 32 miles of bike lanes.

Hence we can establish a model that gives us a prediction or ridership for both situations. Given the complexity of the interactive effect, we will implement a gravity model for the "migration" of cyclists and measure the total distance traveled per capita in each neighborhood. The model is $M_{i,j} = \alpha \frac{f(Aj, Bi)}{\Psi(i,j)}$, where $M_{i,j}$ predicts the number of cyclists who would normally bike in neighborhood i that's currently biking in neighborhood j, $Aj\ and\ Bi$ measures the attractive forces of area j (such as more economic opportunities, biking facilities, better road conditions,etc) and repulsive forces of area i(such as biking injury rates, overcrowded, etc). $\Psi(i, j)$ is simply the distance between the two neighborhoods, and lastly, α is a constant that we fixed to model the rate of population's response to new biking projects. In addition to modeling the migration of cyclists, we predict a growth of cyclists proportion to Aj, the biking-friendliness of neighborhood j, times to population of neighborhood Aj. The final metric used to compare the effectiveness of each approach is the total sum of bike commuters in Queens.

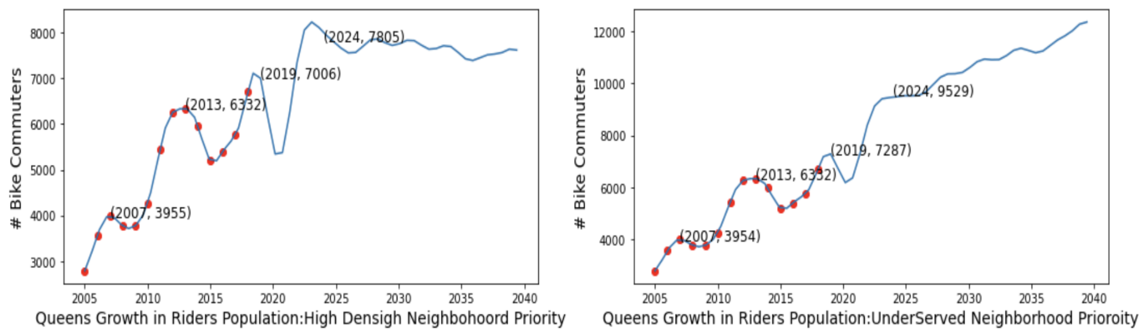


Figure 6: ridership after implementing bike lanes around different areas

4.3 Results

As observed from our analysis above, we observed that the Flushing area ridership experienced an average of 160% growth, while the Corona/Jackson Heights area experienced a 216 % of predicted growth, from which we could conclude that although there is a big demand for accessible transportation to work, it is much more important to prioritize historically underserved areas due to the high potential or growth within these areas, which corresponds to more usership overall. As would be expected, if one were to focus exclusively on areas with high density, our model predicts that the total number of active cyclists would eventually plateau due to the penalty of overcrowdedness that we implemented. In addition, our migration model predicts a significant amount of cyclists relocating themselves to other neighborhoods, especially, to the ones immediately adjacent to which also adversely affects the local growth. By 2040, our model predicts a difference of 4000 total riders between the two approaches, and points of saturation both seem to be reached.

5 Model II: Logistical growth model and Entropy Weight Method

There are many kinds of bike lanes, from those that are separated from the main traffic with only one single solid line to those with a thicker painted buffer, with the most protected ones separating the bike lane and main traffic with actual barricades. For the ease of analysis, we will only make the distinction between protected bike lanes and conventional bike lanes, where protected ones only include physically raised curbs and conventional lanes including those with painted separations, no matter thick or thin.

In order to quantify the correlation between demographics of bikers and benefits of protected bike lanes, we need to first look at the current demographics of bikers in New York City. Here we analyzed the users of popular ride sharing platform Citi Bike and looked at the users born between 1920 and 2000 specifically and plotted the population of each age group on a graph(**Figure 7**).

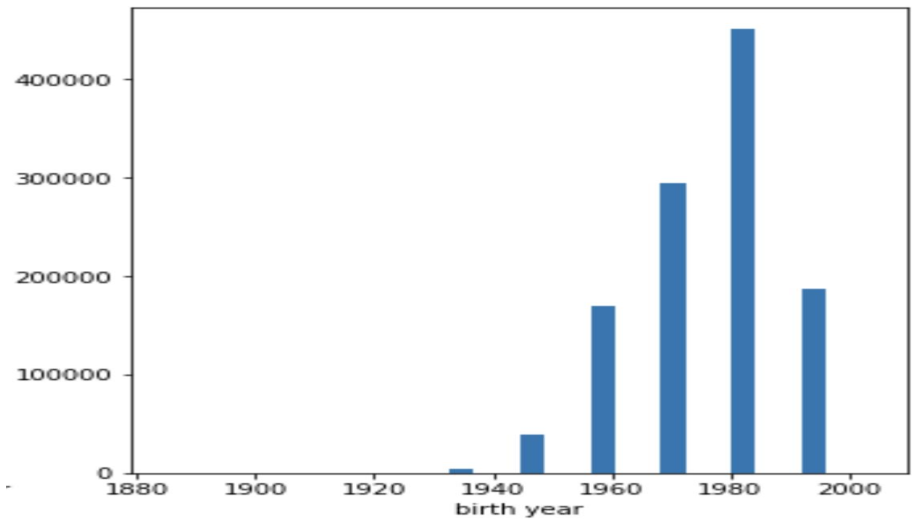


Figure 7: Citi Bike users by age group

We observed that people born between 1979 and 1980 are the main users of citi bike out of the entire population analyzed, therefore we can conclude there is a necessity to encourage younger and older people to start biking more in order to increase the overall biking population. There are many concerns these two age groups might bring up, and we decided to focus on the safety aspect of biking, namely focus on decreasing the injury rate while constructing protected bike lanes in various areas.

5.1 Logistical growth model

For solving this specific problem, we proposed using a Logistical Growth Model(LGM) to quantify the behavior of $I(A)$, a function for the implemental score for evaluating the value of the lane after construction, and $E(A)$, which is the variable that signifies the external costs of the project. Overall, the cost-benefit of a project i, either $p_{conventional}$ or $p_{protected}$, boils down to gauging the various indicators, or coefficients that dictate the following net valuation equation. Based on the eventual $N(A, P_i)$ value for a given project P_i done in a given road area A, we will be able to rank most of the typical candidates and allocate the 27.5 millions of funds in a top-down manner, maximizing the fulfillment of the road-project candidates that have the ranking potential. For now, here is the high-level formula for how we approached to quantify the $N(A, P_i)$ value.

$$N(A, P_i) = S(A,\ P_i) + I(A,\ P_i) - C(A,\ P_i) - E(A,\ P_i)$$

We used Fermi methods to estimate $S(A,\ P_i)$, the value of of a functional area A in status-quo(before our project), $C(A,\ P_i)$, the fixed implementation and maintenance costs of the project. For both $I(A,\ P_i)$ and $E(A,\ P_i)$ we used logistic growth model where

$$\frac{dI}{dA} = mI(1 - \frac{I}{K}), \qquad \frac{dE}{dA} = m'E(1 - \frac{E}{K'})$$

Simplifying, we have $I(A) = \frac{K}{Ke^{-mA}+1}$, $E(A) = \frac{K'}{K'e^{-m'E}+1}$, where $K(K')$ represents the maximum change in value(cost) a project can bring about, and $m(m')$ indicates the maximum rate of change of value(cost) per unit length of bike lane A.

We chose this model based on the following assumptions:

- ☐ The positive and negative impact of the project accumulates through time and we need to quantify an evolving value and one that depends on various complicated factors that are interrelated to each other.
- ☐ The traffic network put a threshold on the maximum allowable impact/consequence we can possibly induce, and the population size also put a cap on the realistic limit on the maximum amount of ridership.

We want to derive the four most crucial coefficients, K, K', m, and m' using a group of elementary indicators. we categorized these indicators into by their functions:

- Provisioning
    - Growth in bikes-on-road count X_1(bikes per lane-group per year). Measuring the effect of a discrete segment of a bike lane is hard and disregards the network effects. Thus, we proposed a functional group of bike lanes which totals an average of 1/3 miles in length.
    - Growth in ridership X_2 (rider count per lane-group per year)
- Regulating
    - Reduction in crashes with injuries X_3 (incident count per lane-group per year)
    - Reduction in the flux of other AV/EV traffic X_4 (vehicle count per lane-group per week). We assumed that traffic patterns do not suffer from seasonal fluctuations and thus a few weekly measurements could sufficiently be inferred to the entire year.
    - Reduction in the usage of public traffic X_5(aggregate revenue loss from MTA services in dollars per borough per year). Availability of biking as an alternative transportation propagates its effect beyond any lane group and its immediate neighborhood. Thus the entire borough will be considered to capture potential latent variables.
- Cultural
    - Monetary effect on retail services for applicable lane-group near a community center X_6 (revenue change in dollars per lane-group per year) For this indicator we drew a conclusion by assigning a fixed estimate.

- Non-monetary effect on standard of living X_7 (a fictitious index per lane-group per year)

5.2 Entropy Weight Method

We wanted to determine the weights of these 7 indicators when aggregating them into comprehensive coefficients K or m that directly relate to the modeling of projected benefit or projected cost. Specifically, we want a weighted linear combination of $X_1$and X_3 to represent m, and a weighted combination of X_2, X_3, X_6, and X_7 to represent K.

The rationale is that only $X_1$and X_3 account for the upper limit of the impact of the project; and only X_2, X_3, X_6, and X_7 has to do with immediate feedback from the system in a short run, thus affecting m, the transient maximum rate of change of the impact. Now the question is to model the weights, despite the inconsistent dimensionality of these indicators.

Enter the Entropy Weight Method (EWM), which helped us eliminate such issues. The procedure is to first use the standard 0-1 transformation to normalize all 7 types of indicator values. Given X_1,..... X_7, where X_i={X_{i1}, X_{i2}, ... X_{in}}, whose elements are the indicator values of type i from the sample road units we studied. We have

$$y_{ij} = \frac{(x_{ij} - min(x_i))}{(max(x_i) - min(x_i))} \ , \ j = 1, 2, ..., n \ ,$$

where y_{ij} is the standardized value of each indicator value of type i, $max(x_i)$ and $min(x_i)$ are the maximum and minimum value of the corresponding evaluation indicator x_i. With the standardized values, we compute the q_{ij} values, each of which is the weight of x_{ij}, a specific indicator value of type i, with respect to the sum of all sampled indicator values of the same type:

$$q_{ij} = \frac{y_{ij}}{\sum_{j=1}^{n} y_{ij}}$$

Based on the information entropy for each type of indicator, e_i, where

$$e_i = - \ ln(n)^{-1} \sum_{j=1}^{n} q_{ij} ln(q_{ij}),$$ (n being the number of samples we studied by hand)

we can finally compute the weight of indicator X_i as w_i,

$$w_i = \frac{1 - e_i}{k - \sum_i e_i}$$, (here k is 7 since we have X_1, X_2, …, up to X_7).

Thus we can combine w_i and y_{ij} to derive the k and m for the j-th sample that we studied in the following way:

$$m = w_1 \cdot y_{1j} + w_3 \cdot y_{3j}$$

$$K = w_2 \cdot y_{2j} + w_3 \cdot y_{3j} + w_6 \cdot y_{6j} + w_7 \cdot y_{7j}$$

Similarly, we derive that

$$m' = w_4 \cdot y_{4j} \text{ and } K' = w_4 \cdot y_{4j} + w_5 \cdot y_{5j}$$

5.3 Case Study

In order to minimize injury rate with our given budget we can do a case study and determine the crash rate of individual road situations with their shape. In areas we want to focus in, there are two specific kinds of shapes that should be brought to attention.

5.3.1 The Triangle

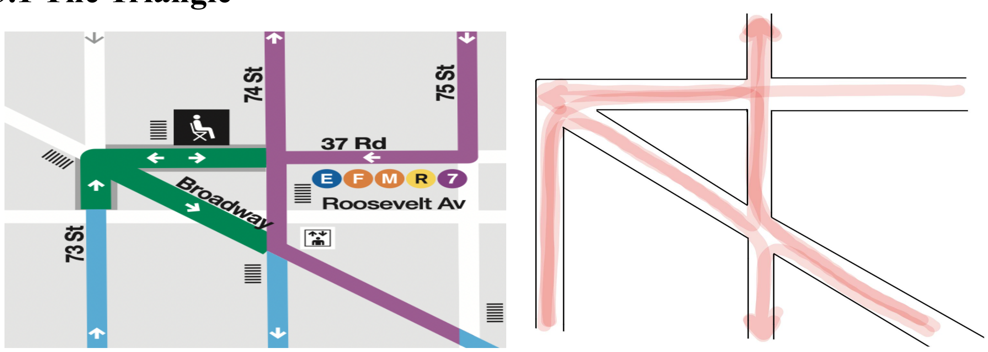


Figure 8: Triangle Analysis

Taking Diversity Plaza in Queens as an example, in terms of graph theory, there are only a certain number of ways you can approach this structure. In this case, there are in total 9 ways of passing through this structure, and according to our calculations, with the protected and conventional bike lane combo already pre existing, the crash rate is -45%. But if we were to establish all protected bike lanes here theoretically, it would lower the crash rate to around -110%.

5.3.2 The Roundabout

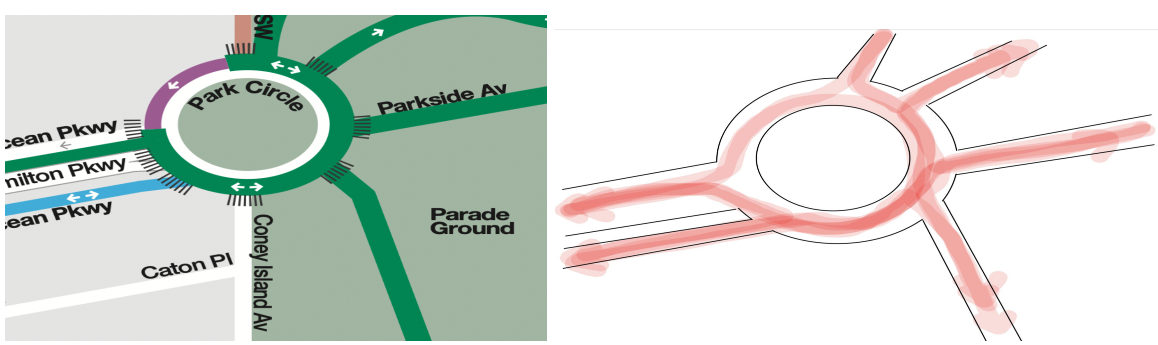


Figure 9: Roundabout Analysis

This is Park Circle in Brooklyn. Since three quarters of the circle is covered with protected bike lanes, the crash rate has already been lowered to -60%. But this design has a striking weakness, that is the one quarter single direction-ed shared lane. That shared lane leaves some possibilities for accidents. If we change that to a protected lane as well, it would further lower the injury rate to around -75%.

Nothing is better to convince people to start riding if the injury rates can be lowered to a certain threshold, and this data would certainly change the male dominated rider population in New York City.

6 Model Evaluation

Challenged by the MCM, we need to find out if our model is the best strategy. We can only hope to present a holistic evaluation with the information we have gathered, and we decided to examine our results from two different perspectives. We are aware that providing more bike lanes means that there will be less lanes for engined vehicles, so we analyzed the strengths and weaknesses for the proposed models above.

6.1 Strengths

Less lanes for engined vehicles means potentially there could be more traffic for the normal non biking vehicles, but that encourages people who are intending to use the road for commercial use to ride bikes more, especially after seeing the buses take longer times to pass through a short amount of distance. Additionally, having protected bike lanes discourages cars from parking in bike lanes, which is very commonly seen when parking space is scarce in a city like New York. Furthermore, with easier access to retail on the side of the road, it brings the community around these bike lanes more equity. Some bike lanes also have trees next to them, which is more appealing to the eye and good for going green for the environment in the long term.

6.2 Weaknesses

As mentioned above, we cannot build protected bike lanes around already crowded or otherwise narrow streets due to the amount of space they take up. The physical barriers add an unnecessary burden to the streets that already overflow, especially in Manhattan. Therefore this model cannot be implemented in specific areas, even though it might cater to higher density or pass through traditionally underserved communities that might need more accessibility.

7 Further Discussion

7.1 Strengths

- ★ Considered the network effect that other transportation systems might have on the biking infrastructure and community;
- ★ We considered prioritizing both density and accessibility to generalize in the greater New York area;
- ★ Our second model doesn't suggest a percentage mix, however it does suggest a list to prioritize, which gives policy makers the choice to use funds wisely;

7.2 Possible Improvements and Limitations

- ☐ We only used the money on improving the bike lanes themselves, since building protected bike lanes require a large amount of funds, but if we didn't have the constraint, clearer signs, more parking/locking stands for bikes, and more cameras to discourage stealing would further encourage ridership in general for all;
- ☐ We did not consider the effect ride sharing would have on the greater area or have it as a parameter for other transportation methods.

8 Executive Summary

To: Ydanis Rodriguez

From: CMMC

Date: Feb 6, 2023

Subject: Recommendations on promoting ridership with better bike lane infrastructure

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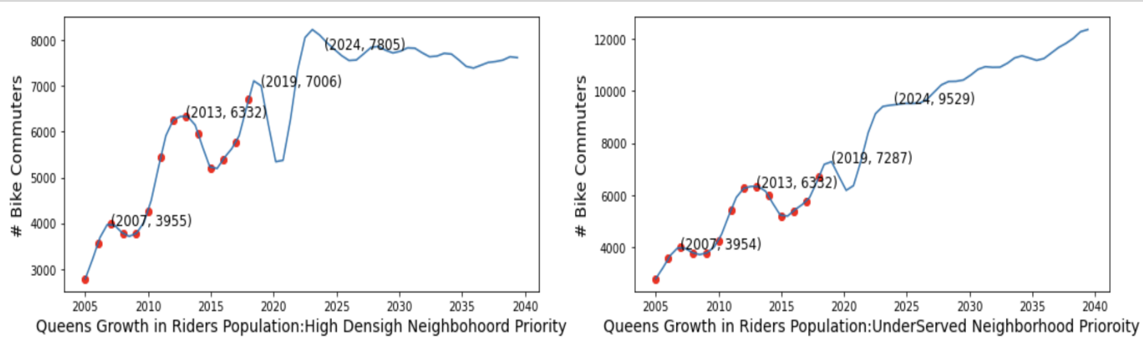
Dear Mr. Rodriguez,

We are researchers from CMMC and we are writing to inform you of our recommendations for encouraging bike ridership in New York City by improving the bike lane infrastructure and management in the city. The current biking infrastructure, though already very expansive, lacks consideration for accessibility in certain areas and we think by reading our executive summary on a modeling research we completed, you will be able to make more informed decisions for all, not just only the bikers in New York.

Our first part of the study includes a comparison when prioritizing areas of high density versus areas with historically underserved communities. We targeted Queens as the borough of interest due to both its high projected rate of growth for bikers as well as it having a diverse enough population as far as demographics go. Furthermore, it has a lot of room for improvement since a large portion of the borough is not covered with bike lanes, unlike Manhattan. We need to note that this is a more idealistic model, with either all of our focus on dense areas or underserved communities, even though we did take the pre-existing bike lanes into account.



The result we obtained is not surprising, if we concentrated all of the horsepower on high density areas, the ridership would plateau due to riders relocating to other areas, in fear of the overcrowding effects, whereas for underserved neighborhoods, there is a large demand yet there doesn't exist much already for an overcrowding effect to happen. Therefore we would urge you to give these people a choice to have biking as a lower cost option for them to commute to work.

Our second part of the study consists of an analysis to minimize injury rates. This model is a more expansive one than the first one and takes more factors into consideration. Using this model, we can analyze a specific terrain and observe how the rate of injury would change by adding protected bike lanes as opposed to a mix of conventional and protected bike lanes. We believe this model can be generalized to the greater New York Area, but within the limited funds, we need to first target those areas with higher injury rates in order to further convince the women, the elderly and the younger riders to come out and join our proud New York bikers on the road.

Though it has some limitations, we are confident that when used correctly, it can help you to make some decisions about how to efficiently promote biking culture, especially in the lens of historically underserved communities, as well as how more protected bike lanes can further encourage those who have some reservations about biking in the city to bike more in the future. Furthermore, we recommend that you look into implementing cameras to discourage bike stealing, as well as installing bike racks on buses to encourage people to take advantage of the expansive bus system already combined with the newly established bike lanes. More locking and parking stands are also recommended to discourage stealing and give people more options when they choose to bike.

Sincerely, Team CMMC

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