An Equitable Expansion of New York City's Cycling Network

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April 2025

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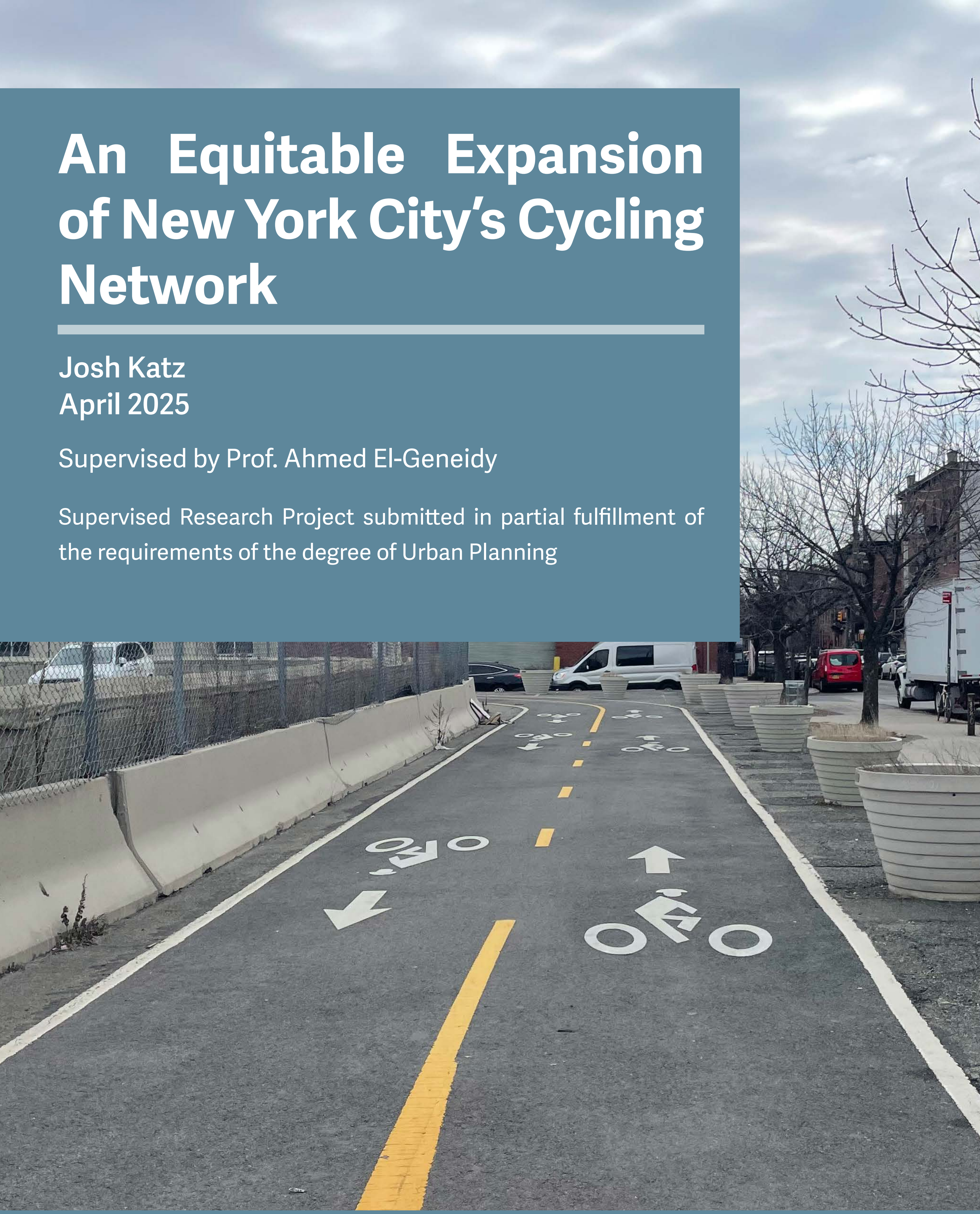
Supervised Research Project submitted in partial fulfillment of the requirements of the degree of Urban Planning



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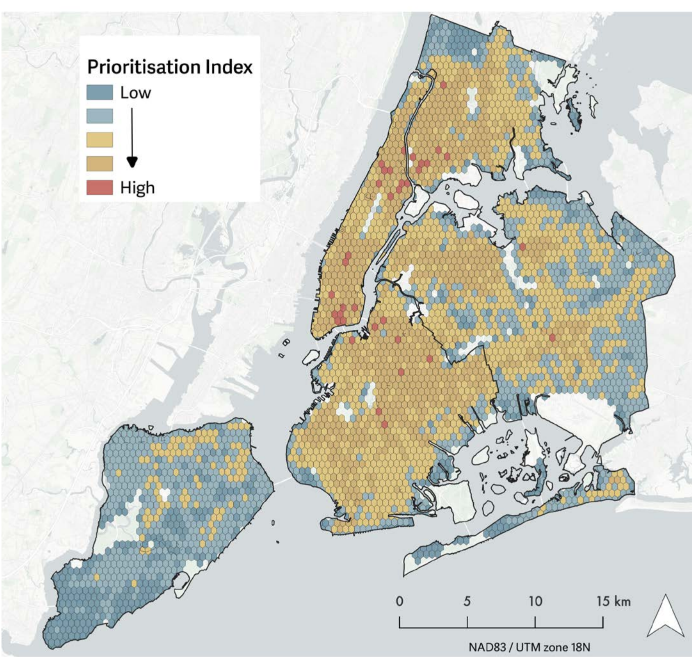
The Issue

New York City's Streets Plan calls for the addition of 50 miles of protected bike lanes per year through 2026. Given the history of inequitable transportation policy and practice throughout North American Cities, it is crucial to consider equity in the expansion of NYC's cycling network. Historical inequities in transportation infrastructure have led to socially disadvantaged communities facing greater exposure to vehicular traffic volumes, pollutants, and traffic violence (Braun et al., 2019; Zimmerman et al., 2015). Prioritising equity in cycling network expansion will make the roads safer and bring greater accessibility to those who need it the most.



Prioritisation Index

Methods

1. Create Prioritisation Index
2. Selection of Priority Corridors
3. Measure Projected Use

Drawing on different methods for prioritising cycling infrastructure (Grisé & El-Geneidy, 2018; Larsen et al., 2013; Zhao & Manaugh, 2023; Zuo & Wei, 2019) I have created a prioritisation index for cycling infrastructure expansion in NYC. This index has 4 different inputs: **Vulnerability Index, Observed & Potential Trips, Bicycle Collisions, and Dangling Nodes.**

The inputs are aggregated onto a hexagonal grid and weighted to produce a final prioritisation index. In corridors with the highest index scores and lack high quality cycling infrastructure bicycle lanes were proposed. The projected use of proposed bicycle lanes were measured, giving a final output of a handful of bicycle lanes to be prioritised in the cities quest to expand its cycling network.

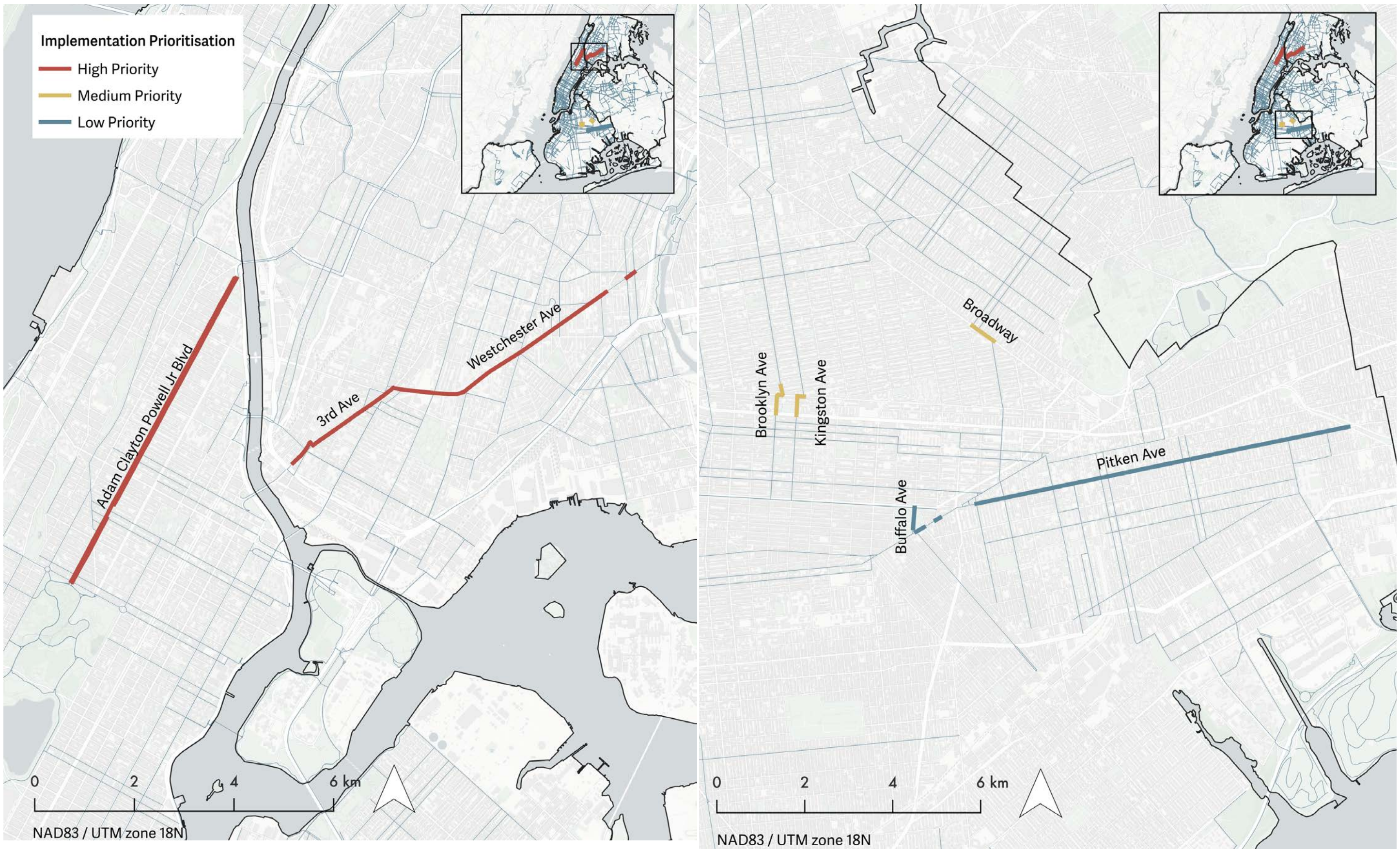
Findings and Recommendations

This research identified 3 areas that both had a high prioritisation index score and lacked high-quality cycling infrastructure. In these three areas, the following high-quality (class I) bicycle facilities have been proposed:

Proposed Bicycle Facilities

1. **The South Bronx:** Westchester Avenue and 3rd Avenue
2. **Upper Manhattan:** Adam Clayton Powell Jr Blvd
3. **North-East Brooklyn:** Pitken Avenue, Brooklyn Avenue, Kingston Avenue, Buffalo Avenue, and Broadway

Based on projected use, existing bicycle facilities in the area, street suitability for greater bicycle facilities, and potential cost of implementation I am recommending New York City prioritise building bicycle lanes on **Adam Clayton Powell Jr.** Blvd in Manhattan, and **3rd and Westchester Avenues** in the Bronx. These streets have the highest projected use and are in areas that are highly socially disadvantaged. Prioritising expansion of the high-quality cycling network on these avenues will push the network towards benefiting all its residents, not just rich and white residents that have been historically catered to in the transportation planning process.



Implementation Prioritisation for Proposed Bicycle Facility Expansion

Acknowledgements

First, I would like to thank Professor Ahmed El-Geneidy for his support and guidence not only in completing this project, but throughout my time at the McGill University School of Urban Planning. His supervision has been vital to completing this project and has helped positively shape my time at the school. Additionally, I would like to thank all of my cohort for their support and advice throughout the process. Finally, I need to thank my friends Eli Conard, Andrew Salerno, and Adam D'Abate and mom Laura Feinland Katz for providing many of the pictures used throughout this supervised research project.

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1.0 Introduction

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New York City (NYC) has one of the most expansive cycling networks in all of North America. The network touches all five boroughs, totalling over 1,500 miles, 623 of which were protected bicycle lanes (NYC Streets Plan Update 2024). While being large, the network still has a ways to go to equitably serve all New Yorkers. Cities throughout North America have struggled to spread bicycle lanes equitably (Braun et al., 2019; Flanagan et al., 2016; Marshall & Ferenchak, 2023), and NYC is no exception to this.

To provide direction for the evolution of NYC's street network, the city has put forward the New York City 2021 Streets Plan. The plan sets a lofty goal of adding 50 miles of protected bicycle lanes per year from 2022 to 2026 (NYC Streets Plan, 2021), but doesn't contain exact detail on locations and methods of selecting location for protected bicycle lane expansion. Given the lack of detail in the NYC Streets Plan on where expansion of the cycling network will be occuring, this research will explore the question of how New York City can best prioritize equity, safety, and increased cycling trips in its quest to expand the cycling network.

This research will propose multiple corridors for cycling network expansion in NYC by creating a prioritisation index that puts equity front and center. A prioritisation index is a multi-criteria analysis (MCA) tool made utilizing a GIS-based model that considers different factors such as sociodemographic variables, historical investment in areas, current and potential demand of cycling trips, safety, and connectivity (Grisé & El-Geneidy, 2018; Larsen et al., 2013; Zhao & Manaugh, 2023). These variables are weighted and combined into an index to show where the network should be expanded to. Using this index, multiple bicycle lanes will be proposed throughout New York City and then prioritised based on the projected use of the facilities. The result of this research will be to recommend a handful of areas where New York City should prioritise expansion of bicycle lanes to create a safe, high-quality, and equitable cycling network.

Bicycle Lane in Brooklyn

2.0 Literature Review

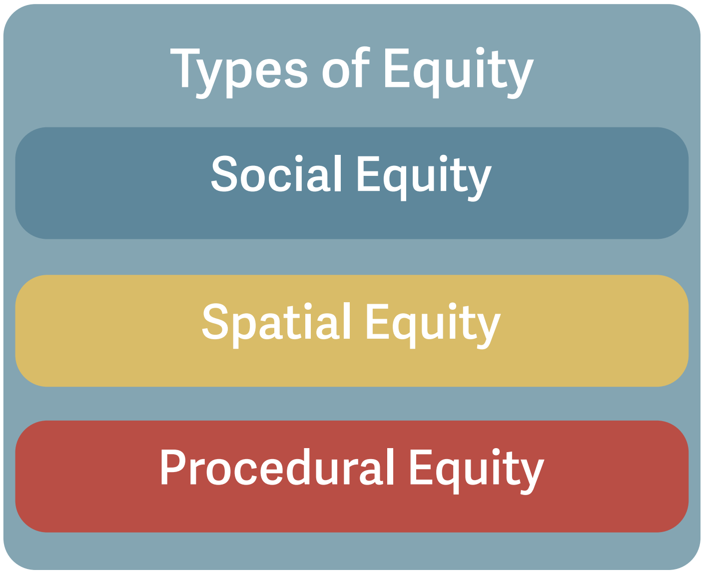
2.0 Literature Review

2.1 What is Equity?

Researchers have been exploring inequities arising from how cities have been built since the 1970's (Fainstein, 2014), yet there is not one agreed upon definition of equity used in the urban planning discipline. The American Planning Association (APA) defines equity in the Planning for Equity Policy Guide as, "a just and fair inclusion into a society in which all can participate, prosper, and reach their full potential." (Planning for Equity Policy Guide, 2019). While this definition mentions allowing all to prosper, it lacks a reference to historical oppression of groups that other definitions include. The Planning for Equity Policy Guide (2019) discusses the importance of analyzing historical oppression but fails to incorporate it into the definition. Incorporating historical oppression into the definition of equity is particularly crucial in the field of transportation planning as historical planning practices and infrastructure investments have particularly disadvantaged people who live near transportation infrastructure, who are most often low income of people of colour in the United States (Karner, 2017).

Agyeman and Doran (2021) offer a differing definition of equity, "equity means making institutional amends to historically marginalized groups." This definition doesn't mention the present like the APA definition does, but instead focuses on the past. Agyeman and Doran (2021) allude to justice as key to the equation of equity. Justice implies that not only have there been historical differences, but that there is a wrong that needs to be made right. To create a transportation system that serves all, planners should aspire towards both the goals of equity and justice.

Offering another definition of equity is Lee et al. (2017) who explore active transportation equity. They define active transportation equity as the "the equitable distribution of active transportation costs and benefits across space and between social groups." (Lee et al., 2017). Within this definition there are three sub-sections of equity: social equity, spatial equity, and procedural equity. Social equity evaluates the impact of different plans, policies, and other project on different socio-demographic groups. Spatial equity looks at the geographic distribution of the impacts of a project, not so much evaluating who is being affected but where people are being affected. Social and spatial equity are commonly evaluated in tandem, looking at both who and where inequities are occurring simultaneously. Procedural Equity refers to fairness of the decision-making process, whose voices are heard and more importantly listened to (Lee et al., 2017). Procedural equity (or participation in the planning process) observes both the level of participation and who is participating (Karner, 2017). Procedural equity connects back to justice, evaluating the way in which inequities happen, though in many cases there is not necessarily a change happening in the system only an evaluation of that perspective. This is



referred to as procedural justice, access to the process and opportunity to have your voice heard playing a key role in a just distribution of outcomes (Karner, 2017). Combining both equity and justice, Agyeman and Doran (2021) offer a framework for an equitable and just transportation system that is defined as one where all are provided sufficient accessibility under most circumstances.

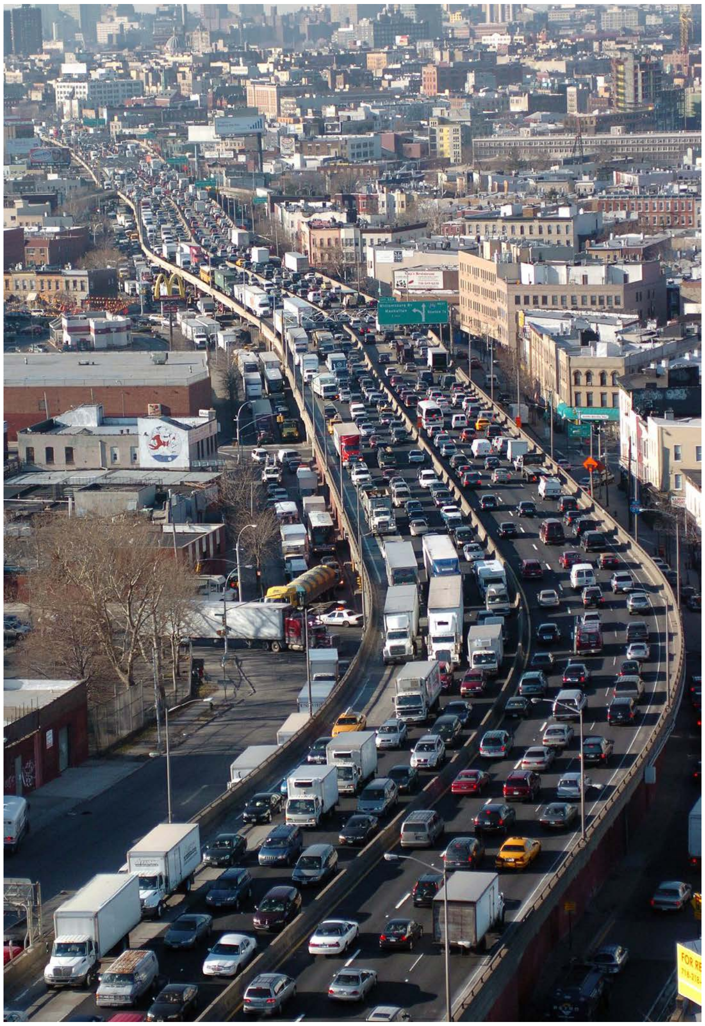
2.2 Equity in Transportation Planning

Historically, equity hasn't been a priority within transportation planning. Agyeman and Doran (2021) theorize that the consequences of equity being a second thought (or not thought of at all) result in disadvantaged people, particularly low-income, Black, Indigenous, People of Colour (BIPOC), immigrant, elderly, children, gender non-conforming people, and women, being denied the same transportation choices as their advantaged counterparts. Most research on the matter agrees that this claim is true for transportation planning as a broad field. Historically, transportation infrastructure has failed to meet the standard of spatial or social equity, with it not being distributed equitably across space or demographic groups (Karner, 2017). Multiple studies have confirmed this, with studies on the social equity of cycling infrastructure finding that in multiple cities cycling infrastructure may be less likely to be in lower income areas compared to more privileged areas (Flanagan et al., 2016; Marshall & Ferenchak, 2023).

Further research on who has access to transportation infrastructure found that areas with higher proportions of black and Hispanic residents (as well as other historically disadvantaged communities) were less likely to contain bike lanes, are further from the nearest bike lane, and have tended to have lower bike lane coverage and reach (Braun et al., 2019). Marshall and Ferenchak (2023) found that block groups that are majority people of colour (POC) saw the least new cycling facilities installed, indicating that the inequality in overall facility distribution is primarily a race/ethnicity issue in the United States. While the results of some studies have differed (Marshall & Ferenchak, 2023), most agree that cycling infrastructure has not been equitably distributed in cities, with low-income, black, and Hispanic communities lacking the same level of access to cycling infrastructure as their whiter and wealthier counterparts.

2.3 Costs and Benefits of Transportation Infrastructure

The impact of the inequitable distribution of transportation infrastructure has led to a host of well documented impacts on the communities they do or do not serve. When looking at one of the most obvious examples of inequitable transportation planning, highways, it is clear disadvantaged communities have felt the brunt of the consequences. Such communities face disproportionate exposure to some or all of the following conditions: vehicular traffic volumes, exposure to harmful transportation-related pollutants, trucking routes, major arterials, intersections that are unsafe or impassable by foot or bike, and an overall lower volume and quality of walking and cycling infrastructure (Zimmerman et al., 2015). These disproportionate exposures serve as barriers to active transportation, sources of air/noise pollution, and impediments to health and safety (Marshall & Ferenchak, 2023).



Traffic Jam on the BQE. Susan Watts/NY Daily News Archive

Disadvantaged people are more at risk for multiple types of traffic risks including pollution and road casualties and death (Agyeman & Doran, 2021). In the US disadvantaged groups, in particular Black and Latino, have a disproportionate risk of being involved in a traffic collisions, controlling for other factors (Barajas, 2018). Black people account for 40% of traffic accidents traffic-related injuries in the United States, compared to only being 13% population share (Braun et al., 2019). When looking at divisions due to income, a similar pattern is reflected with lower-income neighborhoods experiencing road fatality at rates 3.6 times higher than wealthier neighborhoods (Marshall & Ferenchak, 2023). For cycling, studies have found fatality rates for people bicycling are 23% higher for Latinos than whites, and 30% higher for African Americans (Marshall & Ferenchak, 2023). While the level of service of cycling infrastructure may be low in disadvantaged areas, many people are still reliant on biking or walking as a form of transportation, leading the higher fatality rates for those groups.

The inclusion of equity in the active transportation planning process has the potential to have transformative positive effects for historically disadvantaged communities. Bicycle lanes help to foster safe and inviting environments, giving users greater access to goods and opportunities (Flanagan et al., 2016). The access to goods and opportunities is referring to accessibility, the ability to reach desired destinations like jobs, schools, and other destinations (Flanagan et al., 2016). Lacking accessibility may hinder one's economic and social development leading to greater inequity (Lee et al., 2017). By having a greater number of bike lanes, accessibility by bike will be improved (Pereira & Karner, 2021). This can lead to greater economic opportunity in communities that have historically lacked cycling infrastructure.

Having a comprehensive, safe, and fast cycling network will make cycling more attractive to users (Boisjoly et al., 2020). According to multiple studies (Boisjoly et al., 2020), the presence of bicycle lanes, the speed of traffic, and the safety of bicycle lanes are the major contributors to making the network more attractive. Different studies (Larsen & El-Geneidy, 2011; Tilahun et al., 2007) have confirmed that cyclists want safe infrastructure, with cyclists adding up to 20-minutes to their trips to use off-street cycling facilities. In addition to the physical characteristics of the network, cyclists value factors such as the continuity of cycling infrastructure, with one study (Schoner & Levinson, 2014) finding a positive relationship

Cyclists on the Brooklyn-Queens Expressway during the 2022 NYC Bike Tour. Josh Katz

between the directness and connectivity of cycling infrastructure and bicycle commuting. These studies all emphasize why is important to have safe and connected cycling infrastructure, as it will help encourage greater use of the network.

Greater levels of cycling, walking, and rolling will also have numerous health benefits, as well as impacts on greenhouse gas emissions (Agyeman & Doran, 2021). The reduction of greenhouse gas emissions is crucial for New York City given its emission reduction goals (NYC Streets Plan, 2021). Well-designed cycling facilities, like protected bike lanes, have been documented to greatly enhance safety (both perceived and actual) of cyclists, as well as encourage a shift away from motorized forms of transport (Boisjoly et al., 2020; Flanagan et al., 2016; Kiani et al., 2023; NYC Streets Plan, 2021). By focusing cycling network expansion in neighborhoods that have been historically disadvantaged this can assist in relieving some of the consequences of past transportation infrastructure projects.

2.4 Cycling Network Prioritisation Methods

Historically, cost-benefit analysis (CBA) has been the standard way for planners to prioritize transport infrastructure investment. This method is often used when there are constrained resources, but it suffers from many issues when it comes to cycling infrastructure

(Glavić et al., 2019). CBA fails to address the complex factors that contribute to people's willingness to cycle, as these factors are highly subjective. Maybe most importantly, CBA fails to address procedural equity as this processes is often not transparent and doesn't take into account the values of the people that are being served by the infrastructure (Glavić et al., 2019).

In recent years, the flaws of cost-benefit analysis have been realized by researchers, and thus Multi Criteria Analysis (MCA) have been applied with greater frequency (Glavić et al., 2019). MCA allows for consideration of multiple criteria and greater transparency in the planning process as different stakeholders can contribute to decision criteria and weights used for project evaluation (Glavić et al., 2019). Within an MCA there two different avenues for bicycle facility planning; supply and demand (Rybarczyk & Wu, 2010). Supply planning looks at variables such as roadway type, traffic volumes, and bicycle level of service (BLOS). BLOS assesses riders perceived safety of a roadway and is based on factors such as per-lane motor vehicle traffic volume, speed of motor vehicles, traffic mix, potential cross-street traffic generation, pavement surface condition, and pavement width for bicycling. BLOS is utilized in some MCA's but not all (Zuo & Wei, 2019). Supply planning indirectly addresses safety but fails to address if the bike lane will be used. Demand planning focuses on who will use the roadway, utilizing facility demand models and origin-destination data. A combination of supply and demand planning allows for prioritization of cycling infrastructure to wholistically look at implementing cycling infrastructure.

Research on both supply and demand prioritisation of cycling infrastructure has been ongoing for the last 30 years. Often, GIS analysis is utilized to create prioritisation indexes. One of the first iterations of utilizing GIS analysis to prioritize cycling infrastructure was Huang & Ye (1995) who used origin and destination data to determine cycling routes in Berkley California (Huang & Ye, 1995). The use of GIS to prioritize cycling infrastructure investment has only grown in the past 15 years, with a modern-day model on the use of GIS to identify locations of cycling infrastructure created by Larsen et al. (2013). They utilized a grid cell method, imposing a grid to spatially aggregate the pertinent indicators and associate them on grid cells. After testing different sizes of grid cells and using the density of the network in Montreal, the grid cell size of 300m was chosen. The indicators were then aggregated and combined into a prioritization index. The prioritization index was then overlayed with the current cycling network and allows planners to make decisions on where to build cycling infrastructure based on this index. Their model of a **prioritization index** uses the following pertinent indicators:

- Observed and Potential Trips
- Cycling Collisions
- Connecting Dangling Nodes

Grisé and El-Geneidy (2018) built upon this prioritization index by adding in **survey data and an equity component.** They added feedback from cyclists on where they would most like bicycle lanes and which intersections were most in need of improvements. The indicators within the index were then weighed and spatially aggregated to produce a map of the prioritization index. After the index was produced, they measured projected use of the proposed cycling

cycling facilities to help prioritise which of the proposed cycling facilities should be implemented. Projected use was measured by finding the difference in how many observed and potential trips would be conducted on each proposed bicycle lane versus the usage prior to the proposed bicycle lanes. Last, they conducted an equity analysis on the results of the index to make sure the proposed cycling facilities would be placed in areas where individuals would particularly benefit from improved infrastructure. Targeted individuals were those that were socially disadvantaged. Social disadvantage was measured using 4 variables; median household income, unemployment rate, percentage of population that has recently immigrated (Grisé & El-Geneidy, 2018). This prioritization index improves upon the work of Larsen et al. (2013) by adding in social, spatial, and procedural equity into the equation, something that has been lacking in the historical transportation planning process.

In recent years, more research has emerged on prioritization, with methods utilizing a variety of indicators in their prioritization indexes. Some have utilized measures such as BLOS or capital costs in order to make the prioritisation index reflect the budgets of municipalities and make them more realistic (Zuo & Wei, 2019). Zhao and Manaugh (2023) propose different prioritization indexes that can be utilised based upon the values and priorities of researchers, and practitioners. The three different prioritization strategies are (1) improving connectivity of cycling infrastructure, (2) enhancing accessibility for transportation disadvantaged populations, and (3) reducing greenhouse gas (GHG) emissions from the transport sector. Each respective prioritisation strategy utilises different inputs into the index. The second strategy, enhancing accessibility for transportation disadvantaged populations incorporates equity directly into the index, unlike previous studies which conduct an equity analysis post the creation of the index. These prioritisation indexes also weight the different types of road segments differently to create a network that prioritises infrastructure that is more likely to be used by cyclists.

This research will build on prior prioritisation index's (Grisé & El-Geneidy, 2018; Larsen et al., 2013; Zhao & Manaugh, 2023; Zuo & Wei, 2019) to create a custom index for cycling network expansion in New York City. The index will prioritise equity as transportation infrastructure has been inequitably spread in cities throughout North America, including in New York City (Braun et al., 2019; Flanagan et al., 2016; Marshall & Ferenchak, 2023). The output of this research will recommend new bicycle lanes or upgrades to the class of bicycle lanes (upgrading class III or class II facilities to class I facilities) as class I facilities are the safest bicycle facilities that consequently encourage ridership the most (Flanagan et al., 2016; Kiani et al., 2023; NYC Streets Plan, 2021).

3.0
Case Study of NYC

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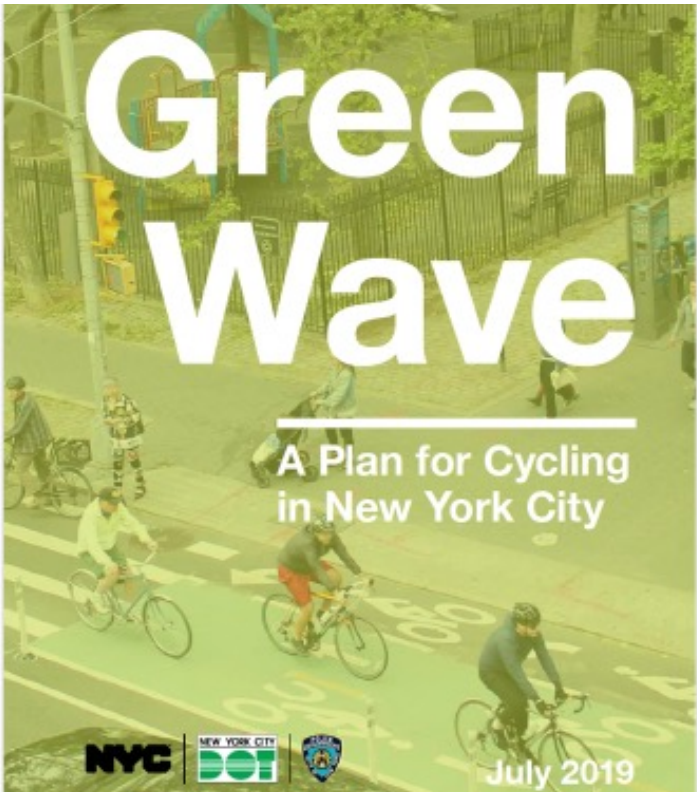
New York City (NYC) is the largest city in the United States, with a population of about 8.2 million as of 2023 (POPULATION ESTIMATES FOR NEW YORK CITY 2023). With such a large population and land mass, the city has a massive amount of infrastructure to look after. The city is in charge of over 6,300 miles of streets and over 800 bridges and tunnels (NYC Streets Plan, 2021). To provide direction for the future of all 6,300 miles of roadway, the New York City Department of Transportation has published numerous plans including the Green Wave, A Plan for Cycling in New York City in 2019 and the New York City Streets Plan in 2021.

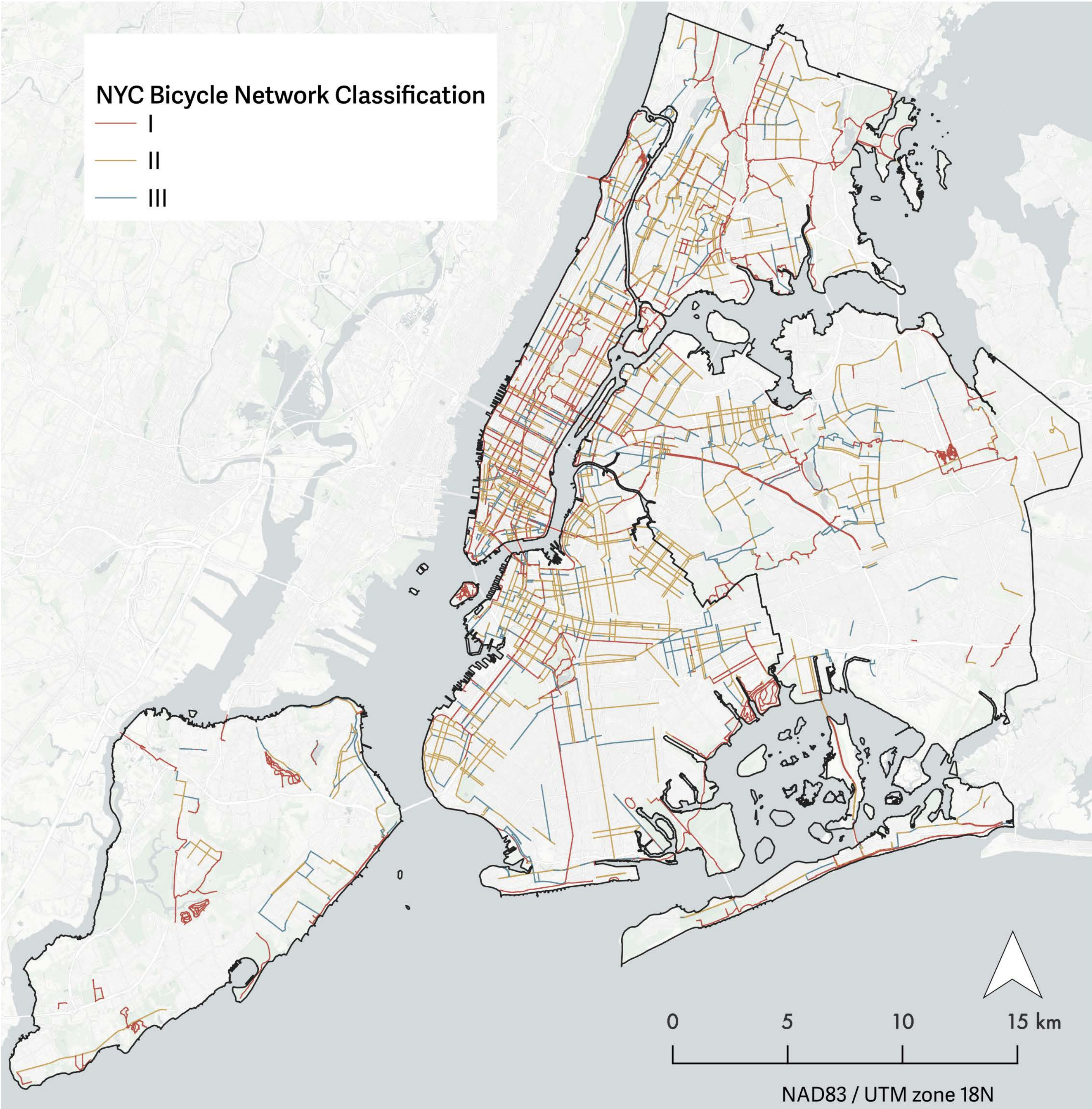
The 2021 NYC Streets Plan provides direction for the next 5-years (through 2026) of infrastructure development on streets in the city. The plan lays out a direction for numerous users of the roadway including transit users, pedestrians, and drivers. The NYC Streets Plan builds on the 2019 Green Wave Plan by providing extensive plans for the future of cycling infrastructure in the city. The plan sets ambitious goals for the future of cycling in the city, including a benchmark of 50 miles of protected bike lanes built per year through 2026, and cycling being 10% of the total mode share by 2050 (NYC Streets Plan, 2021).

The NYC Streets Plan makes a large effort to incorporate equity throughout, designating three prioritized investment area tiers (NYC Streets Plan, 2021). The investment area tiers are calculated based on multiple metrics from the US Census including non-white population share, low-income population share, job density, population density, prior capital project dollars, prior in-house improvements. This approach prioritizes social and spatial equity (Lee et al., 2017), as well as incorporating aspects of justice by prioritising areas that have been historically underserved.



Green Wave Cycling Plan (2019)

NYC Streets Plan (2021)



NYC Bicycle Network (2024)

The plan also alludes to the importance of the incorporation of equity in the lens of safety. 10 districts in Brooklyn and Queens represented 14% of the city's bike lane network and 23% of cyclists killed or seriously injured (NYC Streets Plan, 2021).

The goals of the NYC Streets Plan 2021 are ambitious, but cycling as a commute mode in NYC has been on the rice since the early 1990's. NYC's cycling mode share has increased 267% from 1991 to 2019 (Buehler & Pucher, 2021), reaching an estimated 610,000 cycling trips per day in 2024 (NYC Streets Plan Update 2024). Cycling trips have continued to increase even post-covid as other sustainable modes, like trips by transit, have seen a big hits from their pre-covid trip numbers. As of 2024, 42% of residents live within ¼ of a mile of protected cycling infrastructure, up 2% from 2022, and 99% of New Yorkers live within 1 mile of the cycling network.

NYC's cycling network is very large, totalling over 1,500 miles, 623 of which are protected bicycle lanes (NYC Streets Plan, 2021). NYC's cycling network is classified into 3 types of cycling facilities: Class I, Class II, & Class III (Bicycle Blueprint, 2013). Class I facilities run parallel to roadways but are physically separated. Class II facilities are those that have a painted line to demarcate a bike lane but lack a physical barrier. Class III facilities are those that are shared lanes, have painted sharrows, or roads that have bike prioritisation. Class II and Class III facilities make up the majority of the network., though these types of cycling facilities don't have the same impact as Class I facilities (protected bike lanes) in encouraging ridership and increasing safety (Boisjoly et al., 2020; Flanagan et al., 2016; Kiani et al., 2023; NYC Streets Plan, 2021). Class I facilities are largely concentrated in Manhattan, with the other boroughs lacking the same levels of safe, high quality cycling infrastructure. While there is a large amount of total cycling facilities, there is a way to go to make the entire network safe and desirable to ride.

Class I bicycle facility Red Hook, Brooklyn. Josh Katz

Class II bicycle facility in Williamsburg, Brooklyn. Eli Conard

Class III bicycle facility in Downtown Manhattan. Retrieved from: https://www.nycbikemaps.com/maps/nyc-bike-map/

4.0 Methods, Data, & Results

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This research will utilize the following **methodology** to suggest locations for cycling network expansion in NYC:

1. Create Prioritisation Index
2. Selection of Priority Corridors
3. Measure Projected Use

The final step will be to compare the index and final recommendations to the NYC street plan to evaluate how the two different methods of prioritisation (NYC versus this research) compare to each other.

4.1 Data Sources

The following data sources were used for this analysis:

Socio Demographic Data

The sociodemographic characteristics for NYC by block group were sourced from the American Community Survey (2023). This is the smallest level of data that was publicly available containing all the variables needed for analysis.

NYC Bicycle Network

The bicycle network of NYC is utilized to measure the existing infrastructure and make decisions on where to expand the cycling network. The network is updated yearly and is up to date as of July 2024. This data was retrieved from NYC Open Data portal and was produced by the Department of Transportation (New York City Bike Routes, 2024).

Bicycle Collisions

The New York City Motor Vehicle Collisions (2025) dataset contains all crashes where a police report is filed. This is only crashes where someone is injured or killed, or there is at least $1000 worth of damage. The dataset used was downloaded from the NYC Open Data Portal in January 2025 and contains crash data from 2013 through 2023. The dataset contains 54,335 crashes in total.

Origin and Destination Data

NYC Travel Survey (MTA, 2018) contains origin and destination data for New York City. The survey contains 31,881 total observations and was conducted via random sample using a smartphone app, online, or phone survey.

4.2 Prioritisation Index

To identify areas that should be prioritised for cycling network expansion in NYC this study considers different indicators that demonstrate which areas are more socially disadvantaged, where future cycling trips may take place, where the current network needs to be connected, and which areas are the most unsafe for cyclists. This prioritisation index is modeled after similar studies (Grisé & El-Geneidy, 2018; Larsen et al., 2013; Zhao & Manaugh, 2023; Zuo & Wei, 2019) with a particular emphasis on equity. The index uses the following variables as inputs: **vulnerability index, bicycle collisions, dangling nodes, observed and potential trips.** These input variables will be aggregated onto hexaganal grid cells, normalized, and weighted produce the final index.

4.2.1 Vulnerability Index

The vulnerability index is used as a measure of how socially disadvantaged an area is. This index represents individuals who may particularly benefit from increased cycling infrastructure in their neighborhood. The vulnerability index will be used as the input that measures equity in the final prioritisation index. The vulnerability index is comprised of four **sociodemographic variables:**

- Unemployment Rate
- Median Household Income
- Percentage Non-White
- Percentage Without a Certificate, Degree, or Diploma

These variables are utilized by many studies as a proxy for socioeconomic status (Zhao & Manaugh, 2023). Socioeconomic status is of particular importantance to look at when determining expansion of transportation infrastructure, but especially for cycling infrastructure as such infrastructure has historically been less likely to be in low income and non-white neighborhoods. (Braun et al., 2019; Flanagan et al., 2016; Marshall & Ferenchak, 2023).

The variables used were found per block group, so a method of dividing the data evenly into each grid cell needed to be devised. The division of block groups to grid cells was done by finding the weighted mean of variables in each cell. The weight used was the intersect area of each block group to each cell. Weighted mean was calculated using the following formula:

$$\textit{Weighted Mean} = \frac{\Sigma(x \times \alpha)}{\Sigma(\alpha)}$$

x = input variable

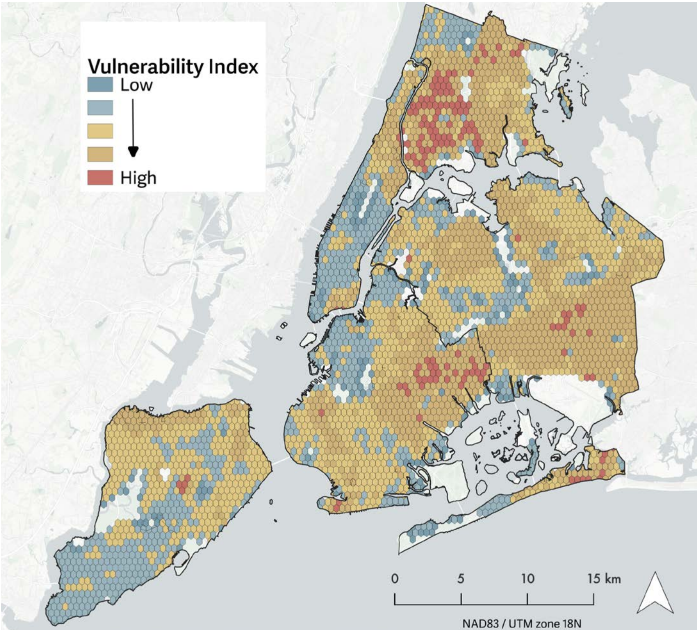
α = intersect area

To combine all variables into the vulnerability index a min-max normalization was conducted on all the input variables. This normalization rescales variables from 0 to 1 so that the minimum value becomes 0, the maximum value becomes 1, and all other values are scaled proportionally in between. Normalization was conducted using the following formula:

$$\textit{Normalized Variable} = \frac{x - \min(x)}{\max(x) - \min(x)}$$

x = input variable

The vulnerability index offers interesting findings, though these findings are unsurprising to those with knowledge of NYC. The highest concentration of vulnerability, sometimes called social deprivation in this paper, are in the Bronx. Large swaths of the



Vulnerability Index

Bronx have the highest vulnerability score (meaning the most vulnerable or socially deprived). Other concentrations of vulnerability include areas in the east of Brooklyn and Queens, and Upper Manhattan. The concentrations of vulnerability and of wealth in Manhattan, the Bronx, and Brooklyn makes sense given these boroughs are among the top-10 places in the United States with the worst income inequality gap (Pascale & Koppel, 2023). Midtown Manhattan, northwest Brooklyn, and south Staten Island are some of the least vulnerable areas in New York City

4.2.2 Observed and Potential Trips

The next input used in the index is commuting trips by observed and potential cyclists. This study only uses commuting trips to either work or school as this data is widely available. For this input, the 2018 NYC Travel Survey (MTA, 2018) was used. Origin (home location) and destination (school or work location) were on the block group level. To calculate the origin and destination of trips a singular point was needed so the centroids of 2018 block groups were used as the origin and destination points.

The route of trips from home to work or school were calculated using r5r, an r package for rapid realistic routing on multimodal transport networks. Once the routes were found, the sum of the length of intersection of each route were calculated per grid cell to find the total length of trips being conducted through each grid cell. Observed and potential trips were then combined into one variable for the index before being transformed using the log + 1 function as the data had a right skewed distribution.

When conducting routing using r5r a level of traffic stress must be chosen to demarcate which streets cyclists are comfortable using. The highest level of traffic stress, LTS 4, was used in this analysis. Level of traffic stress (LTS) is a measure that determines how stressful the use of different streets are by looking at the total number of traffic lanes, the posted speed limit, the presence and type of any existing bike infrastructure (such as separated bike lanes, painted bike lanes, or sharrows), and the proximity of bicycle infrastructure to bicycle parking if applicable (Eldred, 2020). **LTS** is then categorized into **four different levels** based on those variables:

Level of Traffic Strees

LTS 1: Tolerable for children. This includes low-speed, low-volume streets, as well as those with separated bicycle facilities (such as parking-protected lanes or cycle tracks).

LTS 2: Tolerable for the mainstream adult population. This includes streets where cyclists have dedicated lanes and only interact with traffic at formal crossing.

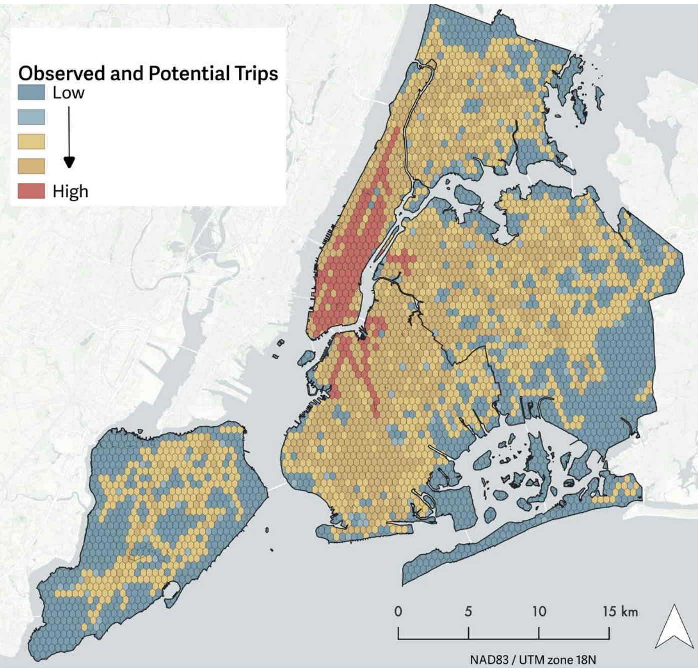
LTS 3: Tolerable for "enthused and confident" cyclists. This includes streets which may be in close proximity to moderate- or high-speed vehicular traffic.

LTS 4: Tolerable for only "strong and fearless" cyclists. This includes streets where cyclists are required to mix with moderate- to high-speed vehicular traffic.

LTS 4 was chosen as the level of traffic stress used for routing as the goal of finding the observed and potential trips is to find where cyclists would choose to travel if the most direct routes were available, not necessarily where they are traveling currently. Setting the routing at a LTS 4 will result in the most direct path taken when routed, thus seeing where cyclists would most desire to ride if the most direct path was possible.

In total, there were 741 observed trips, with a median trip length of about 4 miles (6.5 km). Observed trips are those that contained an origin and destination point (no NA's) and were conducted via bicycle. There were 480 potential trips. Potential trips were classified as any car trip of a distance that was below the median bicycle trip length. Potential trips taken via bicycle would take on average less then 30 minutes using off street or on street facilities traveling at an average pace of about 10 mph (El-Geniedy et al., 2007).

Observed and potential trips are mainly concentrated in Manhattan. Manhattan has the highest concentration of jobs in the city, and the highest number of people commuting into the borough, with about 1.6 million workers traveling each day (Deal, 2013). The concentration of jobs and commuters are why the highest number of trips are in Manhattan. There are a few corridors with a large amount of potential trips in the other boroughs. The cooridors in Brooklyn and Queens with high numbers of trips are key avenues that lead to the Brooklyn, Manhattan, Williamsburg, and Queensborough bridges, the only direct bike connections into Manhattan. Cyclists in Brooklyn and Queens concentrate their routes onto these corridors to travel into Manhattan for work or school. A pattern that emerges from the observed and potential trips

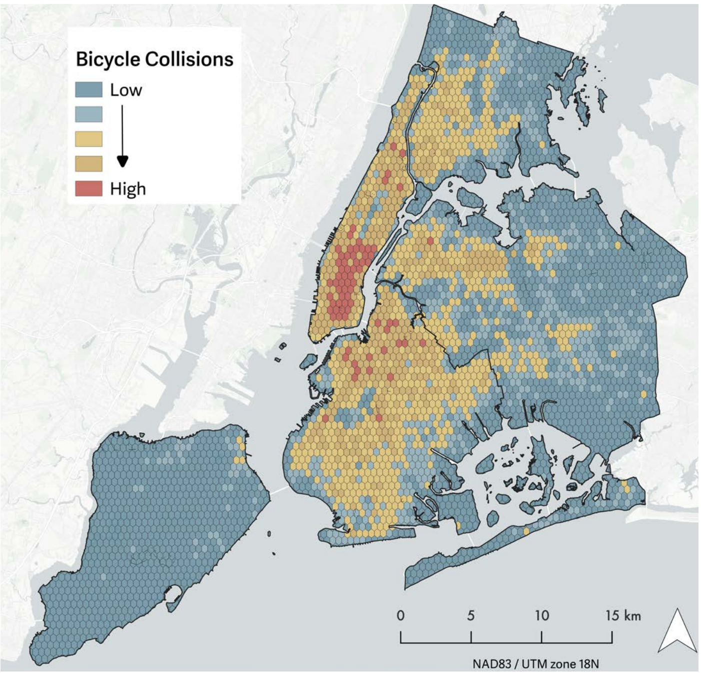


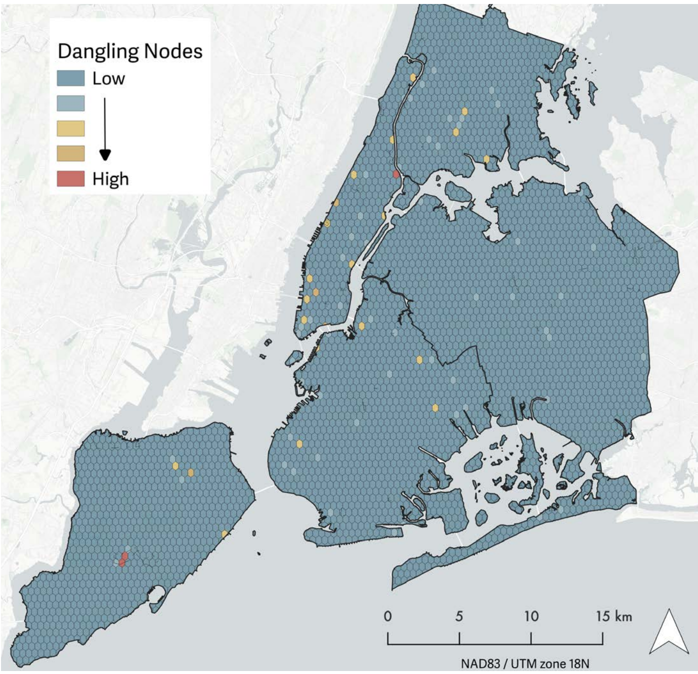
Observed and Potential Trips

shows that as you move further from Manhattan there are lower numbers of bicycle trips. This is due to the lower density in the outerlying areas of NYC and the willingness (or unwillingness) of cyclists to bicycle large distances for a commute (Dill & McNeil, 2016). Staten Island strays from the pattern as it is farther from Manhattan (only reachable by car, bus, or ferry) and doesn't have the same level of job concentration as Manhattan.

4.2.3 Collisions

Safety is one of the most important decisions affecting cyclist travel behavior (Boisjoly et al., 2020). The perception of unsafe cycling conditions may deter some commuters from commuting by bicycle (Larsen et al., 2013). Safety is incorporated into the index through all reported crash data from New York City that involves bicycles since 2013. Collisions included in the index are anything involving a cyclist with either vehicles, pedestrians, or other cyclists. They are then aggregated to each grid cell by finding the number of crashes in each cell. This variable was transformed using the log + 1 function as the data had a right skewed distribution.





Bicycle Collisions

Bicycle collisions are the highest in lower Manhattan and get progressively lower (besides portions of Brooklyn) as you move further away from Manhattan. This is likely due to the high amount of bicycle, pedestrian, and vehicular traffic in Manhattan. With such a high density of activity there is a higher chance for crashes to occur. The areas in the outer lying boroughs have lower traffic, bicycle use, and density of activity thus having less crashes.

4.2.4 Dangling Nodes

Dangling nodes are anywhere in the cycling network where the lanes discontinue or end abruptly. This is important to consider as a direct and continuous route of safe cycling infrastructure is among the top concerns of cyclists choosing their route and reason for cycling (Boisjoly et al., 2020; Sener et al., 2009). Dangling nodes were aggregated to each grid cell by finding the number of dangling nodes in each cell. This variable was transformed using the log + 1 function as the data had a right skewed distribution.

Dangling nodes are sparse throughout New York, with no clear patterns of areas with high concentrations of dangling nodes emerging. There are a few smaller areas with a high number of dangling nodes including lower Manhattan, central Staten Island, upper Manhattan, though most grid cells contain no dangling nodes.

4.2.5 Aggregating and Weighting Final Index

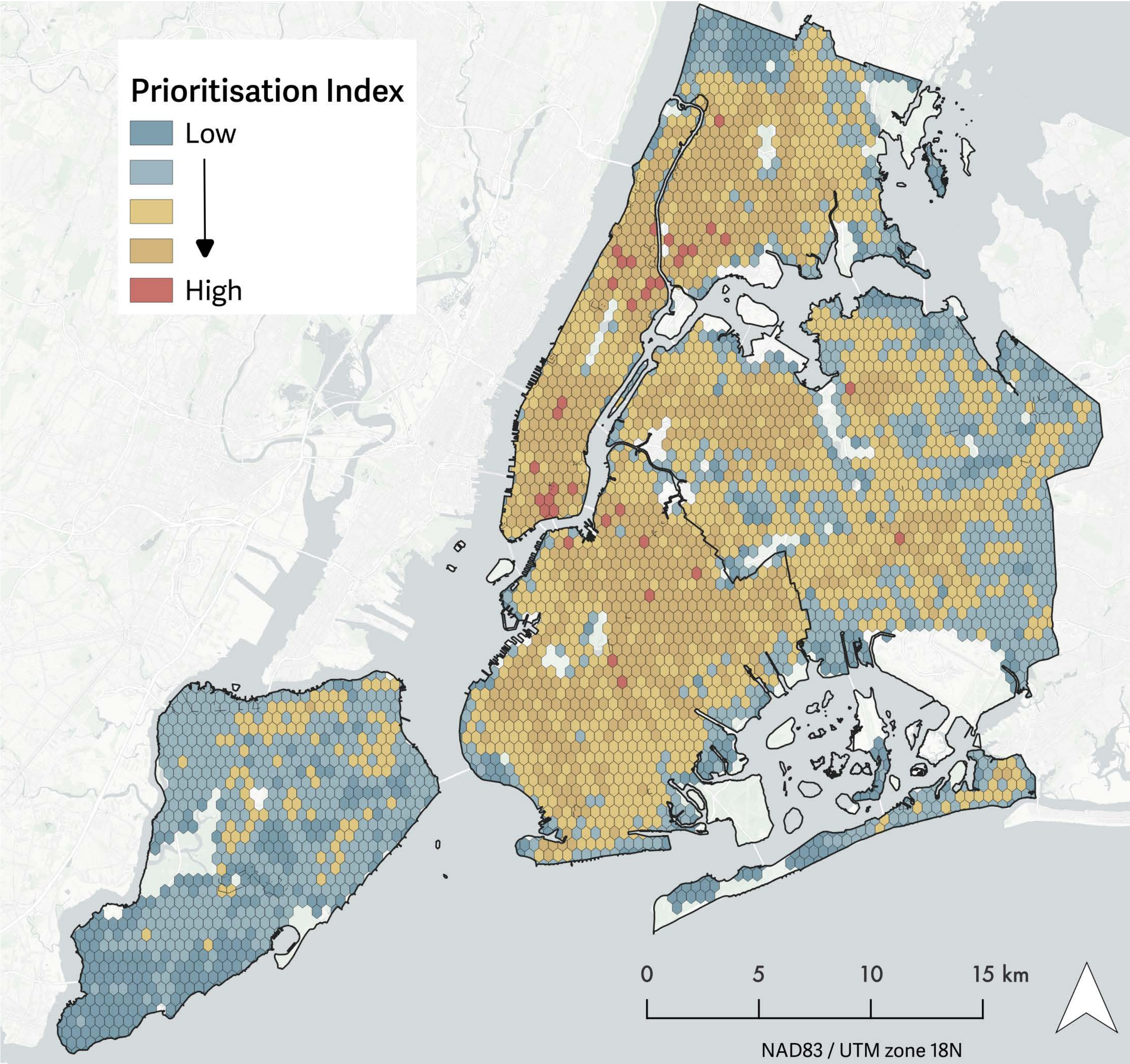
Once the inputs had been prepared, they were aggregated. To do so all the inputs had to be normalized using a min-max normalization to a 0-1 scale. This was done using the same formula as the sociodemographic variables.

$$\textit{Normalized Variable} = \frac{x - \min(x)}{\max(x) - \min(x)}$$

When aggregating the inputs to create a final index a weighting scheme was used. This weighting scheme applied a higher priority to the vulnerability index.

$$\textit{Final Index} = \begin{array}{c}(\text{Vulnerability Index} \times 0.4)\\ +\\ (\text{Observered and Potential Trips} \times 0.2)\\ +\\ (\text{Collisions} \times 0.2)\\ +\\ (\text{Dangling Nodes} \times 0.2)\end{array}$$

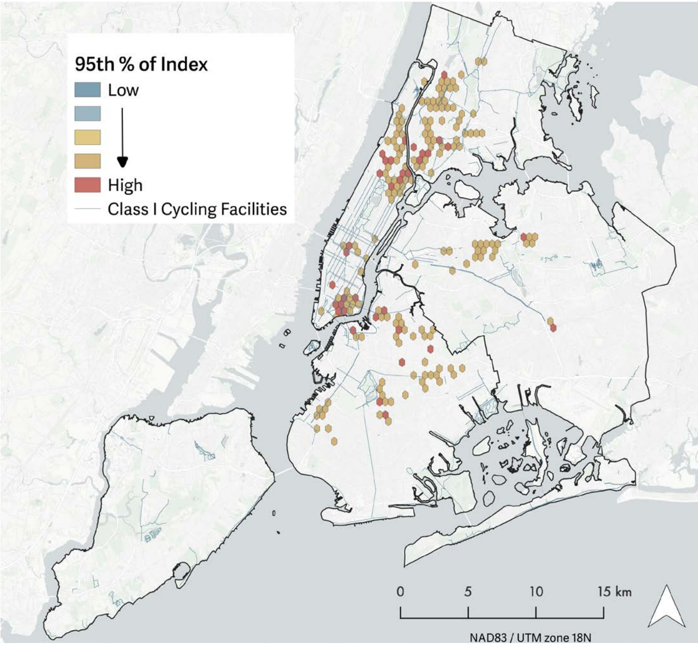
The weighting scheme weighs the vulnerability index the highest while all the other inputs are weighted equally. This was done as equity, making institutional amends to historically marginalized groups (Agyeman & Doran, 2021), has often been ignored in transportation planning. It is the duty of planners to make historical amends to disadvantaged groups by actively targeting them when considering transportation infrastructure improvements. In this index the vulnerability index serves as a proxy for historically disadvantaged groups. The NYC Streets Plan (2021) also cites equity as a main goal, wanting to prioritise resources for communities in greater need for transportation mobility and access. For both the reasons reiterated in this research and given the goals of the NYC Streets Plan it makes sense to weight the vulnerability index higher than other inputs, however others using this same index may choose to weight the index differently according to the researchers and the municipalities values.



Prioritisation Index

The final weighted prioritisation index shows a handful of areas with a concentration of the highest need for improved cycling infrastructure. These areas include lower Manhattan, upper Manhattan, and the south Bronx. When looking only the 95th percentile of the index (the highest index scores), the areas with the concertation of the highest index scores become clearer and a few new areas stand out having high index scores. These other areas are scattered throughout Brooklyn and Queens, but don't have the same high concentration throughout a large area like those in the south Bronx and Upper Manhattan. Some areas that aren't as high on the final prioritisation index include all of Staten Island and areas on the outskirts of other boroughs. These areas lack the trips, crashes, and dangling nodes to make them a priority for bicycle lane expansion.

Lower Manhattan has a combination of a high number of trips and a high level of vulnerability in Chinatown and the parts of the surrounding area of the neighborhood. The high concentration of jobs in Manhattan and the number of commuters traveling



95th % of the Prioritisation Index with Class I Bicycle Facilites

over the Brooklyn and Manhattan bridges make lower Manhattan high on the prioritisation index. Upper Manhattan has a similar story with high vulnerability and a high number of trips. The South Bronx doesn't have the highest number of trips but has high vulnerability making it the area with the highest concentration of high index scores outside of Manhattan.

4.3 Bicycle Lane Selection

When selecting the areas for high quality cycling network expansion I limited myself to selecting only three corridors to keep the workload manageable as each added facility requires a large amount of manual work to add it to the network. These corridors were chosen based on three factors:

Bicycle Lane Selection Factors

1. High Prioritisation Index Score
2. Low concentration of high-quality cycling infrastructure (class I bicycle facilities)
3. Street conditions to support increased cycling infrastructure

The three factors for selection of corridors were actualized in multiple ways. Only corridors with a high concentration of cells in the 95th percentile of the index were considered for expansion. If there are a high amount of class I bicycle facilities in cells, they were not considered even if they were in the 95th percentile of the index. This was due to the lack of need for more class I bicycle facilities in the area. The final factor considered were street conditions such as street width. A selected street would need to be wide enough to contain class I bicycle facilities with at least one lane of travel for motor vehicles remaining to be considered. The selection process was done by utilizing my knowledge of New York City, as well as google earth, and New York City bicycle route data. Other researchers using the same methods may choose to use different factors in their bicycle selection process.

In addition to the three corridors, a handful of smaller areas were chosen where expanding the cycling network would be prioritised mainly to connect dangling nodes where there was an obvious need. These were chosen based on a high prioritisation index score as well as a short distance between two or more dangling nodes in the same area.

After narrowing down the index to only those areas in the 95th percentile or above, I next evaluated which areas to eliminate from prioritisation based on the presence of class I facilities. While lower Manhattan is high on the prioritisation index, there is already a high amount of class I bicycle facilities in the area so lower Manhattan was not prioritised for expansion of the cycling network. Upper Manhattan, the south Bronx, and parts of Brooklyn and Queens are areas with high scores on the prioritisation index and also lack a comprehensive network of class I bicycle facilities.

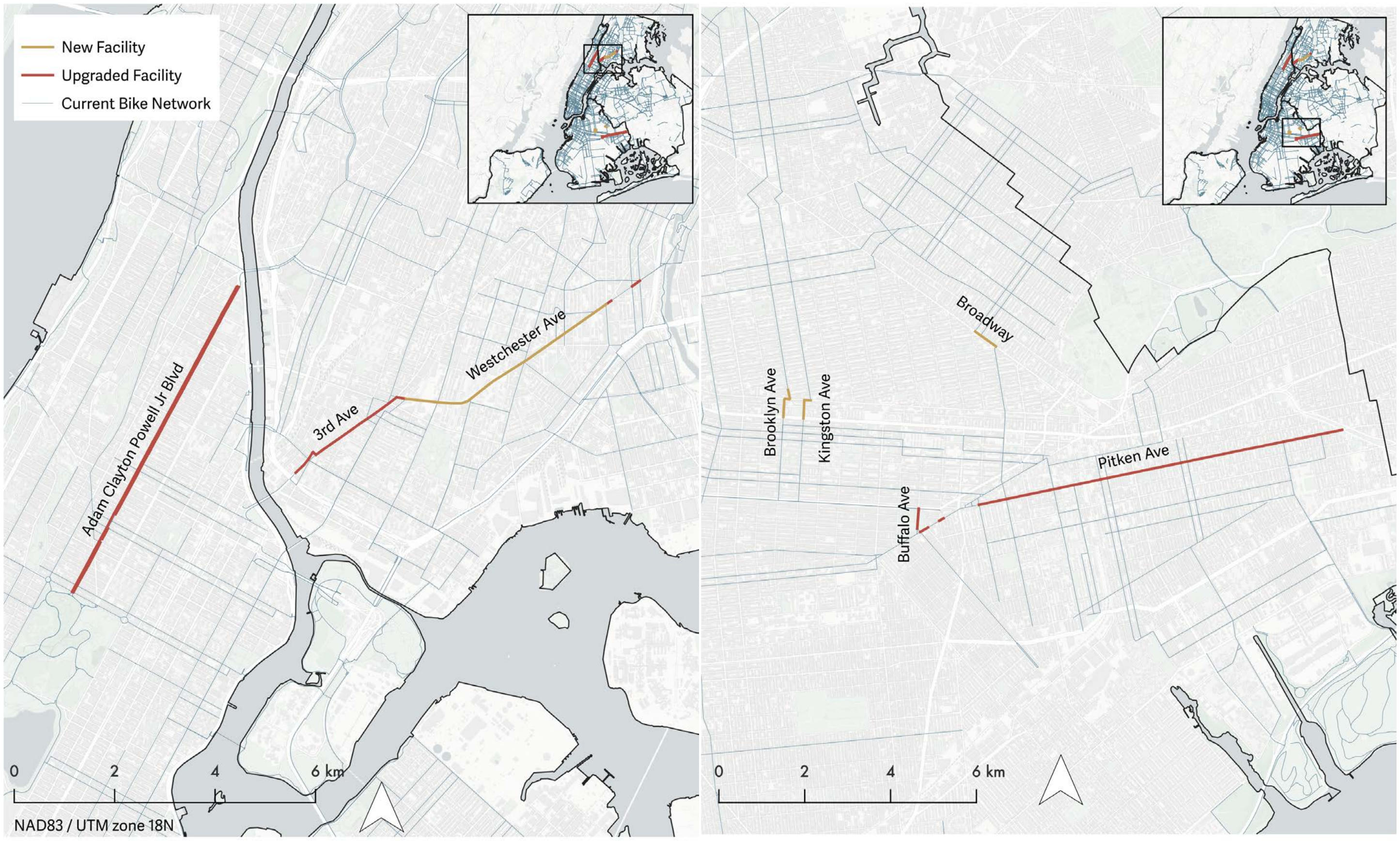
Due to the factors listed above the following corridors were selected for prioritisation of bicycle facilities:

Proposed Bicycle Facilities

1. **The South Bronx:** Westchester Avenue and 3rd Avenue
2. **Upper Manhattan:** Adam Clayton Powell Jr Blvd
3. **North-East Brooklyn:** Pitken Avenue

Additional Smaller Facilities in Brooklyn

1. Brooklyn Avenue
2. Kingston Avenue
3. Buffalo Avenue
4. Broadway



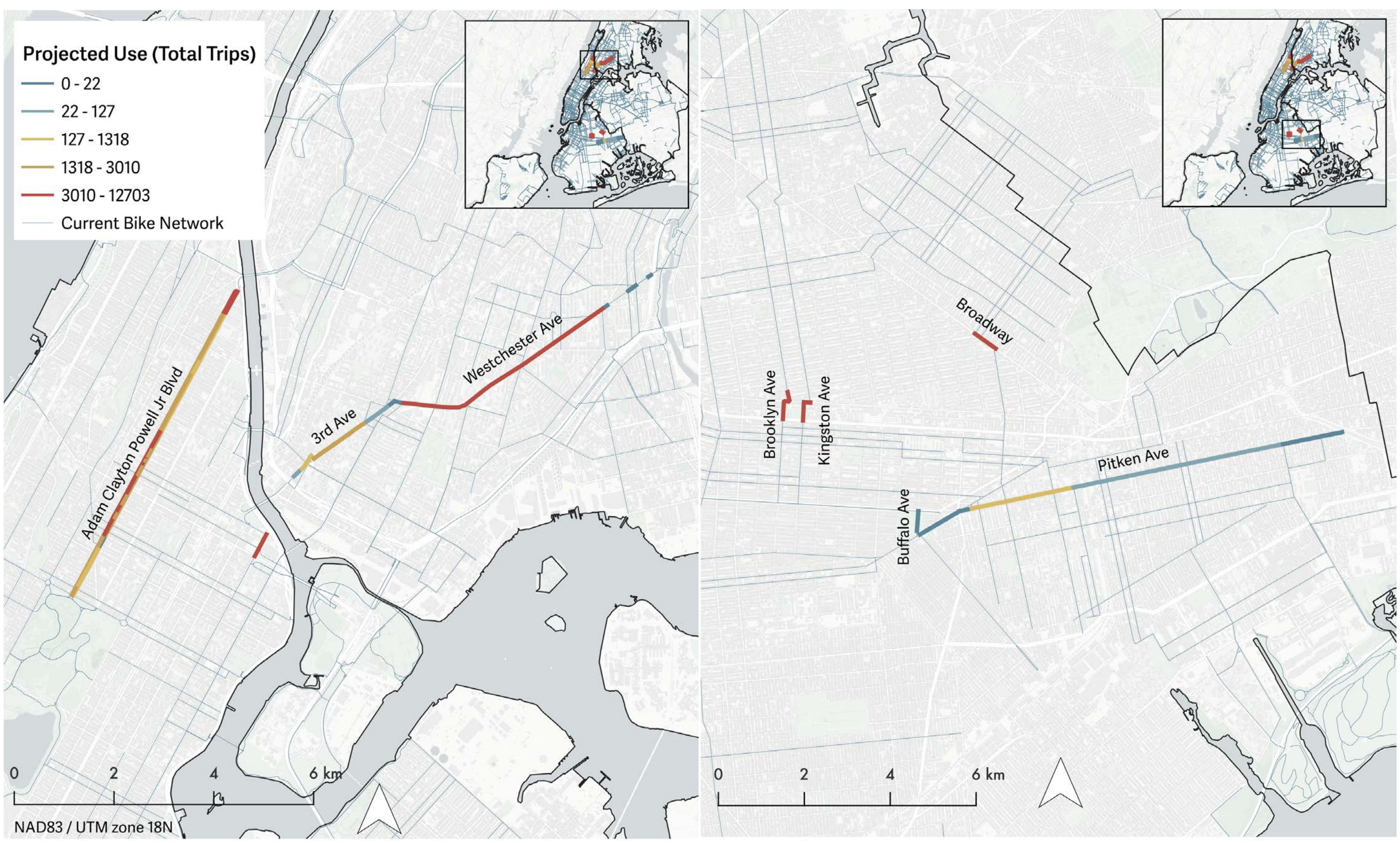
Proposed Bicycle Facilities

Some of the proposed bicycle network expansion corridors did already contain cycling infrastructure so I am proposing an upgrade to the facility type in those cases. Adam Clayton Powell Jr. Blvd in Manhattan does already contain some bicycle facilities, the road having class II bicycle facilities south of 117th Street and class III bicycle facilities north of 117th Street in both travel directions. Despite the presence of some bicycle facilities, these are not the class I facilities that offer users the highest levels of safety and comfort. 3rd Avenue in the Bronx had class II facilities but given the new class I facility on Westchester Avenue it made sense to upgrade 3rd Avenue as well. This upgrade would lead to continues high quality bicycle facilities connecting from the heart of the south Bronx to the 3rd Avenue Bridge which many bicycle commuters use to travel to Manhattan. Pitken Avenue also currently has bicycle facilities that are class II or III (the type of bicycle facility changing throughout the corridor). Pitken avenue offers a connection to the separated bicycle path on Eastern Parkway which connects to Prospect Park and Downtown Brooklyn. The upgrade of bicycle facilities on Pitken avenue allows for a continuity of high-quality bicycle facilities that connect to eastern Brooklyn, one of the most socially deprived areas in the borough.

4.4 Measuring Projected Use

After selecting the bicycle lanes for expansion, I estimated the projected use of each lane. This was done to predict which of the selected lanes would have the highest use once implemented, allowing for prioritization to be done amongst the bicycle lanes. To measure use, I once again calculated the routes for trips from the 2018 NYC Travel Survey using an updated OSM database containing the proposed bicycle lanes in the network. The OSM database was edited using r, QGIS, and JOSM (a software used for editing OSM data). The trips routed included both observed and potential cyclists as we are projecting use in the future once these bicycle lanes are implemented. For routing, cyclists would be using only LTS 2 facilities (tolerable for mainstream adult populations) and below as we are attempting to measure which bicycle lanes would be used if implement, so we assume that LTS 2 is a level of stress that most cyclists in NYC would view as tolerable. All the proposed bicycle lanes are either LTS 2 or LTS 1 facilities, so they would all be able to be used by cyclists in this routing exercise.

When calculating the projected usage, trips were weighted using expansion factors provided in the NYC Travel Survey. This makes the sample of trips from the survey better represent the population of New York City as a whole. The trips and weights were split by day of the week (weekday, Saturday, Sunday) and the weight used was according to which day the most trips occurred per person. It should be noted that calculating projected usage does not include commuters that may switch modes in the future because of new high quality cycling facilities (besides commuters included in potential trips, those traveling by car less than a distance of 6.6km). Additionally, the projected usage only reflects commuter trips, not those traveling for recreation or other purposes. The actual use of proposed facilities may not perfectly match the projected use, but the goal of this exercise is to allow for an estimation of the projected use to better inform which facilities should be prioritised in implementation. When applying this methodology researchers and practitioners may want to analyze mode shift in addition to projected use if the main goal of the network expansion is shifting commute modes. The main objective of this research is to make a more equitable cycling network, so this analysis is not necessary for this research.



Projected Use of Proposed Facilities

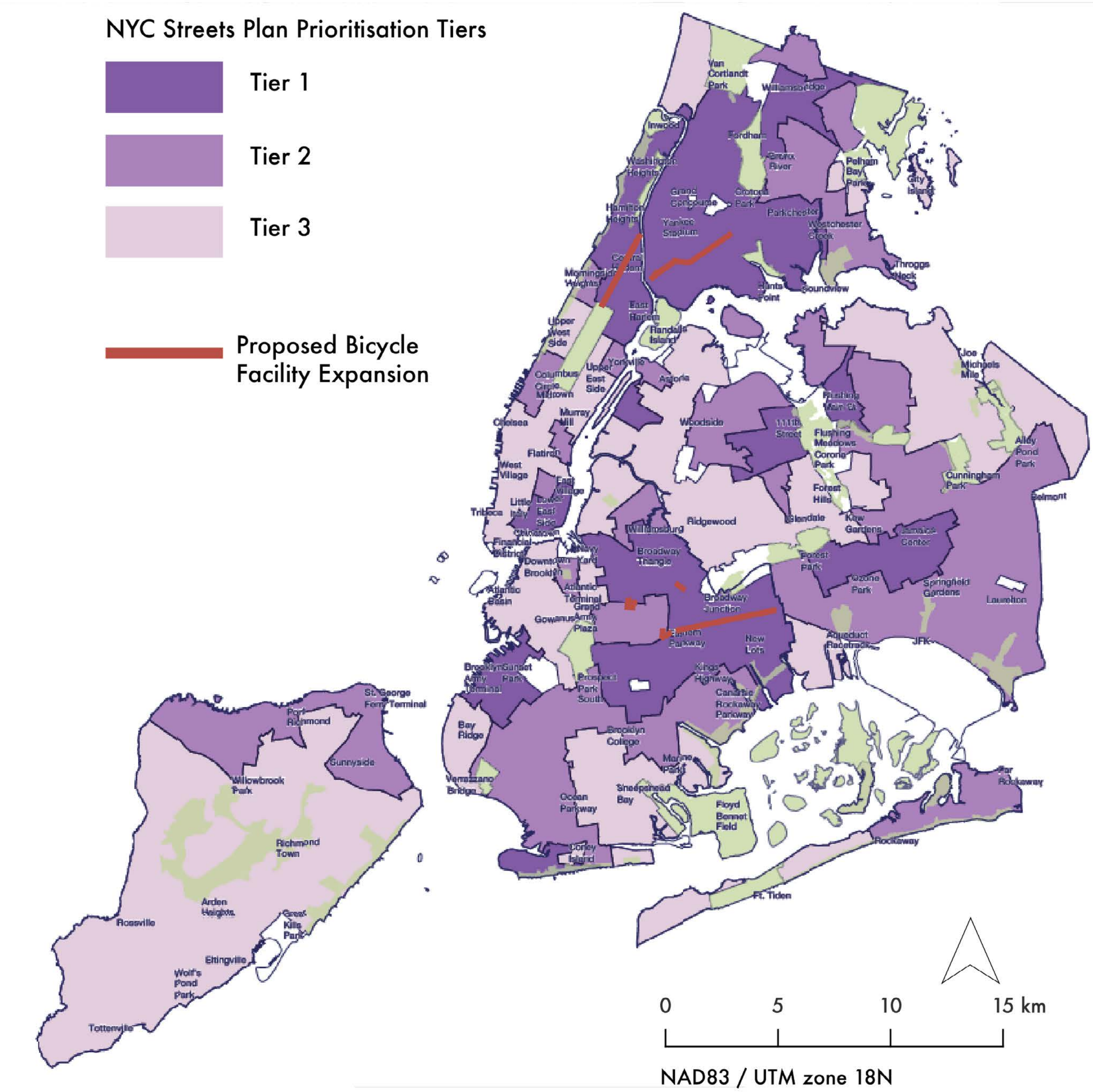
The projected use of proposed facilities makes it clearer where expansion of the cycling network should be pursued. Westchester Avenue in the Bronx has the highest projected usage for cyclists after adding high quality bicycle lanes throughout the corridor. While there are already some cycling facilities on the streets that surround Westchester and 3rd Avenues, the additions of class I facilities to these avenues make for a more direct path which is used more often by cyclists. The connections to numerous other bicycle lanes from Westchester and 3rd Avenues also contribute to the high projected use in this corridor, as the connections to and from other areas make the bicycle lanes more likely to be used. Clayton Powell Jr. Blvd also offers high potential usage, being well connected to the cycling network, and having a direct connection from the Macombs Dam Bridge to Central Park.

Proposed bicycle facility upgrades and expansions in Brooklyn don't have as high a potential use as those in Manhattan & the South Bronx. This is due to a few factors including farther distances to the main commuting center (Manhattan) leading to less cycling trips. Additionally, much of this area of Brooklyn lacks a comprehensive network of high-quality bicycle infrastructure. By adding high-quality bicycle facilities in this area, this may increase cycling use and lead to more bicycle facilities in the area, but that analysis is outside of the scope of this research. The smaller facility upgrades (connecting dangling nodes) do project to have high use, which makes sense given the bicycle lanes that already exist in the area. The addition of these small new facilities have the potential to have high use with relatively little investment.

4.5 Comparison to NYC Streets Plan

The NYC Streets Plan (2021) has its own priority framework for identifying priority investment areas (PIA's). PIA's are used for investment in all types of transportation infrastructure, not just cycling infrastructure. PIA's are analyzed by Neighborhood Tabulation Area (NTA), which are a geogrpahic unit between US census tracts and New York City Community Districts. Equity, like the index in this research, is at the forefront the city's prioritisation framework, weighting sociodemographic inputs higher then other inputs. Their framework uses three different inputs. First, sociodemographic data which is the percentage of the population that is non-white and percentage of households that are low income. Second density, measured in population and jobs per square mile. The last input is previous investment levels measuring expense funded and capital projects from the past 10 years in each neighborhood. NTA's are then divided into three tiers, 1, 2, and 3. Tier 1 NTA's are of the highest priority for the city have a greater population that is lower income and less white.

The methodology used for New York City's own prioritisation of transportation infrastructure investment is similar to the methodology used in this research. As a result, the proposed bicycle facility expansions from this research match almost across the board the highest prioritisation areas for NYC, tier 1 (besides Brooklyn, Kingston, and Buffalo avenues). PIA prioritisation in the NYC streets plan is meant to be a starting point to view where projects should generally be pursued (NYC Streets Plan, 2021). This research builds off these tiers by providing more specific recommendations for where cycling infrastructure should be implemented. Including observed and potential trips in the method, and comparing projected use provides a more granular level of detail for cycling network expansion that is not able to be included in a large citywide plan.



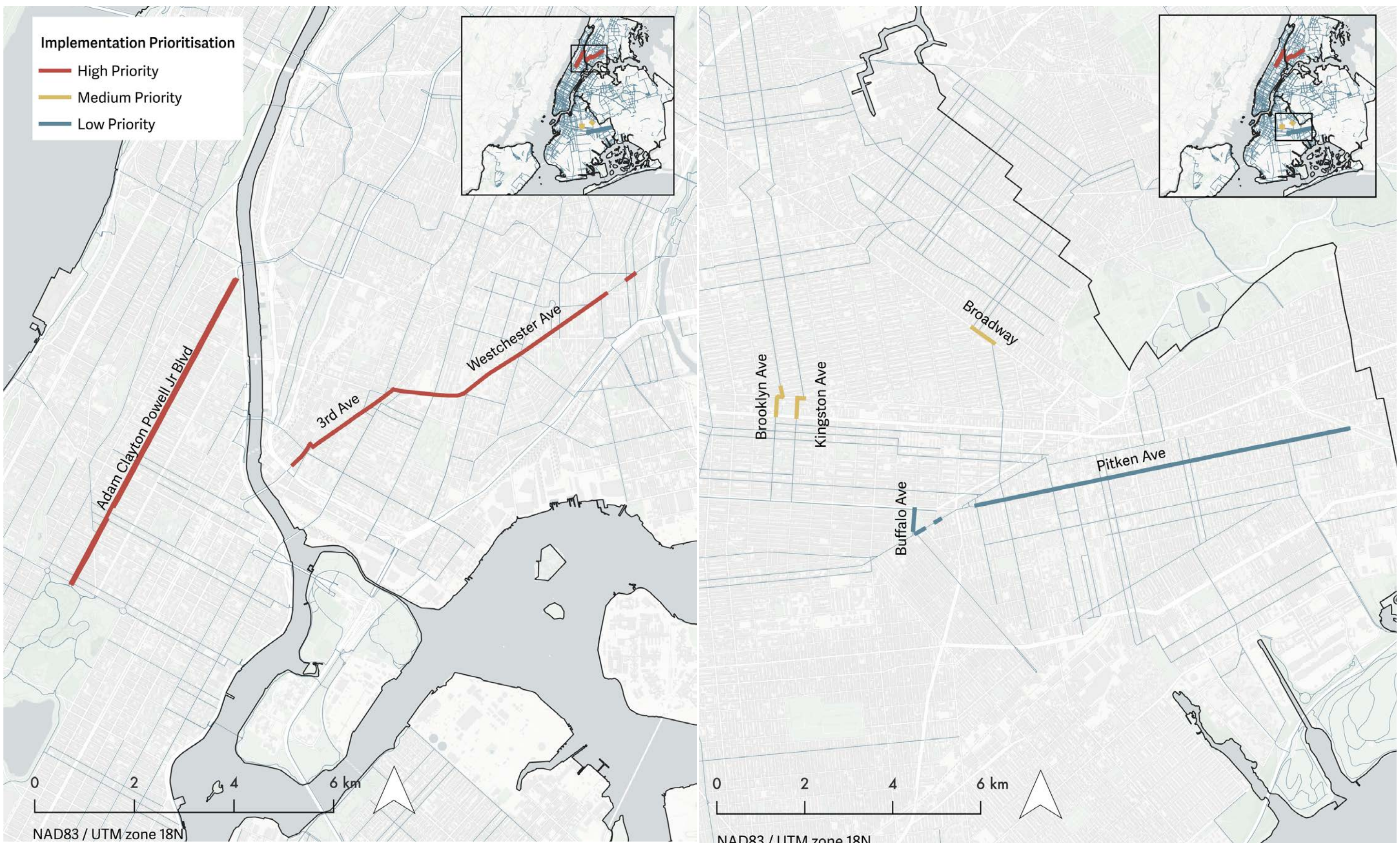
Comparison of NYC Streets Plan to Proposed Bicycle Facilites

5.0 Recommendations

5.0 Recommendations

This research provides a methodology for prioritising cycling investment utilizing a prioritisation index with a particular emphasis on equity. The prioritisation index builds off of earlier research on prioritising cycling network expansion (Grisé & El-Geneidy, 2018; Larsen et al., 2013; Zhao & Manaugh, 2023; Zuo & Wei, 2019) by adapting previously used methods to the New York City context. Based on the prioritisation index, a low amount of high quality cycling facilities, and a street conditions that could feasibly support class I bicycle facility I have produced the following recommendations.

New York City should prioritise cycling network expansion on **Adam Clayton Powell Jr. Blvd in Manhattan,** and **3rd and Westchester avenues in the Bronx**. These bicycle lanes offer the best combination between having a high prioritisation index score, a low amount of class I cycling facilities, street conditions that can support such infrastructure, and have high projected use once implemented. Both of these cycling network facility expansions are located



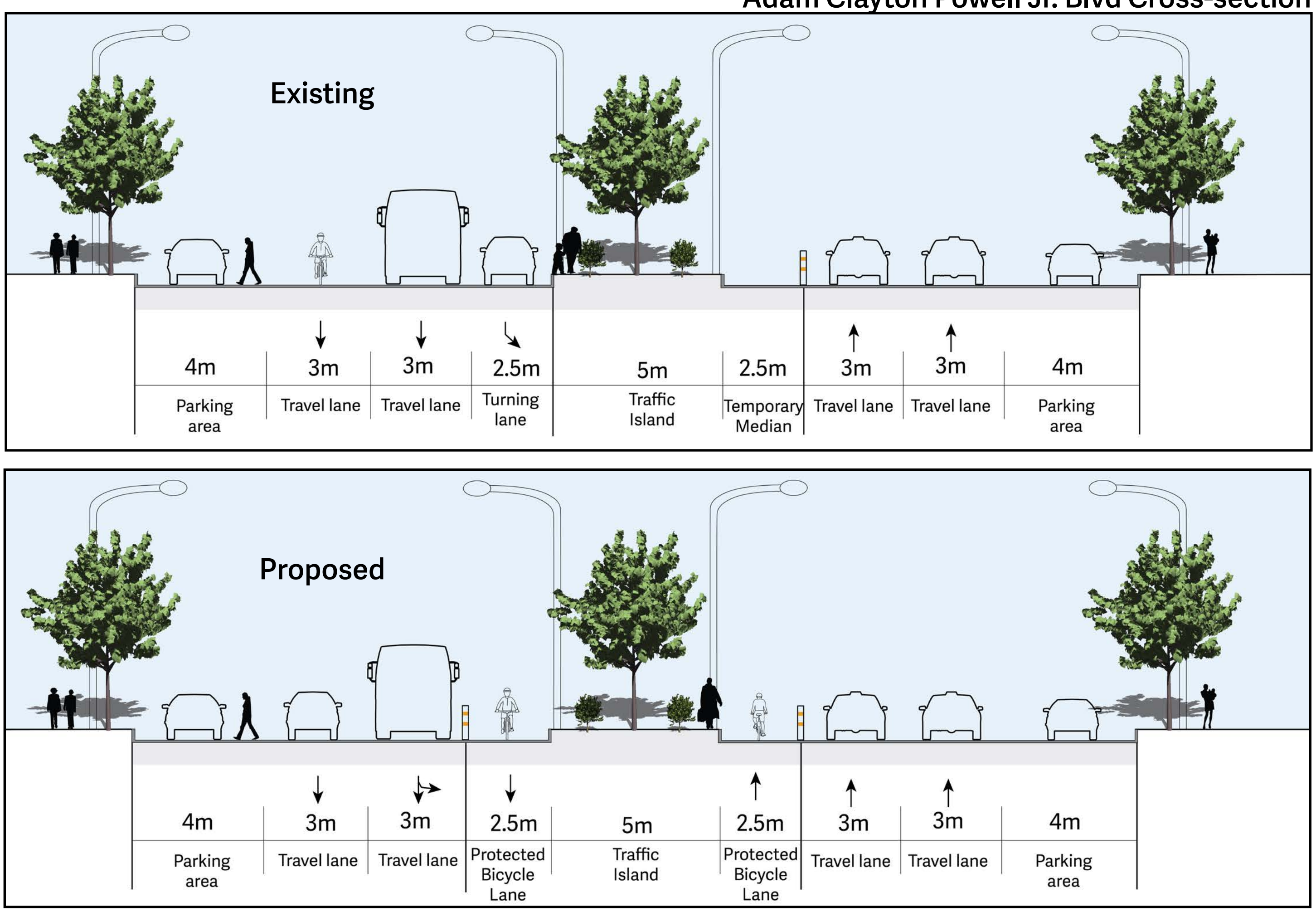
Implementation Prioritisation for Proposed Bicycle Facility Expansion

Location	Borough	Facility Type	Class	Facility Change	Priority
Adam Clayton Powell Jr. Blvd	Manhattan	Two-way Protected Bicycle Lane	I	Upgraded and New	High
3rd Avenue	Bronx	Two-way Protected Bicycle Lane	I	Upgraded	High
Westchester Avenue	Bronx	Two-way Protected Bicycle Lane	I	New	High
Brooklyn Avenue	Brooklyn	One-Way Protected Bicycle Lane	I	New	Medium
Kingston Avenue	Brooklyn	One-Way Protected Bicycle Lane	I	New	Medium
Broadway	Brooklyn	One-Way Protected Bicycle Lane	I	New	Medium
Buffalo Avenue	Brooklyn	Two-way Protected Bicycle Lane	I	Upgraded	Low
Pitken Avenue	Brooklyn	Two-way Protected Bicycle Lane	I	Upgraded	Low

Details of Proposed Bicycle Facility Expansion in areas with high social deprevation, accomplishing the original goal of this research of creating a more equitable cycling network. Expansion of the network to add facilities on Brooklyn avenue, Kingston avenue, and Broadway should be of medium priority. These streets are rated medium priority as they don't have the same level potential use as the those in Manhattan and the Bronx, but still have a high amount of potential use and are smaller investments. The medium priority streets will offer the city high use bicycle lanes in exchange for a smaller investment then the corridors in Manhattan and the Bronx. The lowest priority amoungst the proposed cycling network expansion are on Buffalo and Pitken avenues in Brooklyn. Upgrades to these facilities don't project to have high use and are apart of a large corridor that will be expensive to implement.

The crosssection of one of the high priority bicycle facilities, Adam Clayton Powell Jr. Blvd, shows the current car oriented nature of the boulevard. The street is about 30 meters wide, making it difficult for pedestrians to cross safely, and has no high quality cycling infrastructure (class I cycling facilites). The speed of traffic on the boulevard is high as a result of the width and lack of road furniture throughout, making the current allignment unfriendly to pedestrians and cyclists. By adding class I bicycle facilities, protected bicycle lanes, to the avenue (see cross-section below) traffic will be slowed and the street made safer, the end result of which being street that is more welcoming to pedestrians and cyclists.

Adam Clayton Powell Jr. Blvd Cross-section



6.0 Conclusion

6.0 Conclusion

This project created a methodology for where to prioritise cycling network expansion in New York City. The methods built on similar research conducted previously in different contexts (Grisé & El-Geneidy, 2018; Larsen et al., 2013; Zhao & Manaugh, 2023; Zuo & Wei, 2019) by creating a prioritisation index for cycling network expansion. This index was assembled using sociodemographic census data, origin and destination of commute trips, collision data, and by finding where there are dangling nodes of bicycle lanes. The index was then weighed to prioritise expansion in areas where individuals are most in need of the infrastructure (the highest social deprivation). The result was an index that suggested prioritisation of **cycling network expansion in Upper Manhattan, the South Bronx, and East Brooklyn.**

From the results of the index a handful of corridors were selected for expansion based on a high index score, a low concentration of class I cycling facilities in the area, and being a street that could support cycling facilities. Based on these criteria the expansion of cycling facilities on Adam Clayton Jr. Blvd in Manhattan, 3rd and Westchester Avenues in the Bronx, and Pitken, Brooklyn, Kingston, and Buffalo Avenues and Broadway in Brooklyn were proposed. These facilities were prioritised based on projected use and size of project leading to the final recommendation of this research being to **prioritise cycling network expansion** on **Adam Clayton Jr. Blvd in Manhattan, and 3rd Avenue, and Westchester Avenue in the Bronx.**

The purpose of the research is to provide a tool to assist planners and decision makers in prioritising cycling network expansion. This research provides specific recommendations using this tool to help spread New York City's cycling network more equitably. It should be recognized that this prioritisation index is one tool that should be used with others to assist a wholistic decision-making process. This prioritisation index is not meant to replace surveys, community engagement, and other tools for public consultation, but is meant to be a complement to such tools. Prior to implementing the findings of this research or any other prioritisation index it is crucial that planners and policy makers engage the public in the decision-making process. This is a crucial step in figuring out where it makes sense to expand bicycle facilities. Public engagement acts as a critical tool to getting buy in from local residents and businesses and avoid the phenomenon of "bikelash", a term meaning pushback on bike lanes coined from opposition to new cycling infrastructure in New York City (Wild et al., 2018). Conducting proper and meaningful public engagement in addition to the recommendations of any prioritisation index will lead to better procedural equity (Karner, 2017; Lee et al., 2017) and help mitigate "bikelash" from residents. By leveraging the findings of this research and engaging in a meaningful public engagement New York City will be on a path towards creating a cycling network that benefits all its residents, not just rich and white residents that have been historically catered to in the transportation planning process.

7.0
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7.0 References

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