# Bridging Efficiency and Sustainability: A Strategic Framework for Citibike Allocation Optimization in Urban Mobility

citi bike
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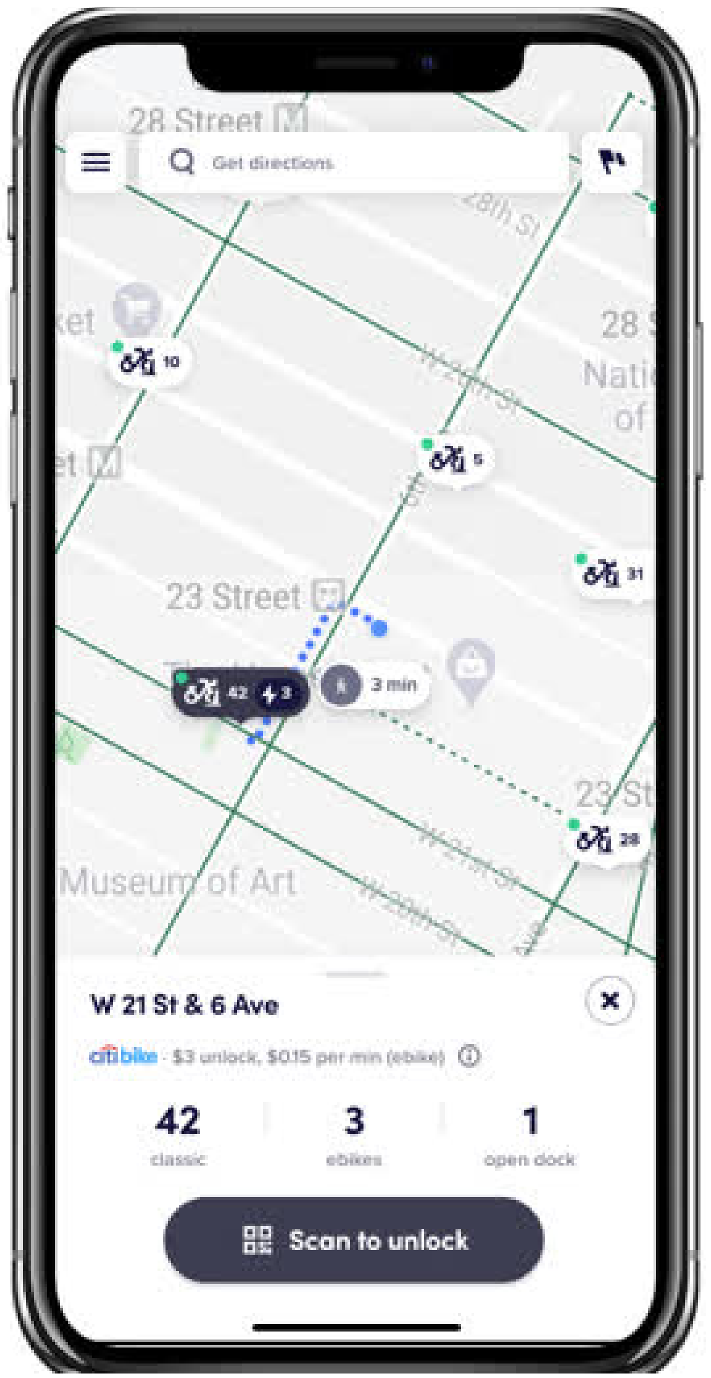


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# Reasons for Undertaking

**01**

### *Enhanced Customer Satisfaction*

By ensuring that each station has an adequate number of bikes to meet demand, we aim to provide a superior experience to our users, minimizing unmet requests and enhancing overall satisfaction.

**02**

### *Asset Optimization*

Efficient allocation of bikes translates to optimized asset utilization. This approach minimizes the financial impact of idle or underutilized bikes while maximizing their use.

**03**

### *Improved Financial Performance*

An optimized allocation strategy is expected to impact the company's financial performance positively. By reducing operational costs and enhancing revenues, the company gains financially.

# What is Bike Rebalancing?


Motorized Vehicles

Bike Vallet

bike angels

Reward Programs


Bike Trikes

# Project Methodology

### Data Preparation

**DATA COLLECTION & INTEGRATION**

- Combined datasets from Citibikes website and GCP.
- Included vital components like Citibike station capacity, availability, and detailed trip data

### Model 1:

**ASSIGNMENT OPTIMIZATION**

- Developed to determine optimal bike demand for revenue maximization during morning peak hours (8 a.m. to 10 a.m.)
- Outputs serve as inputs for Model 2, indicating morning bike requirements at each station

### Model 2:

**FLOW OPTIMIZATION**

- Aimed at finding the most cost-effective bike redistribution paths overnight.
- Focuses on balancing supply and demand across stations while minimizing operational costs

### Results

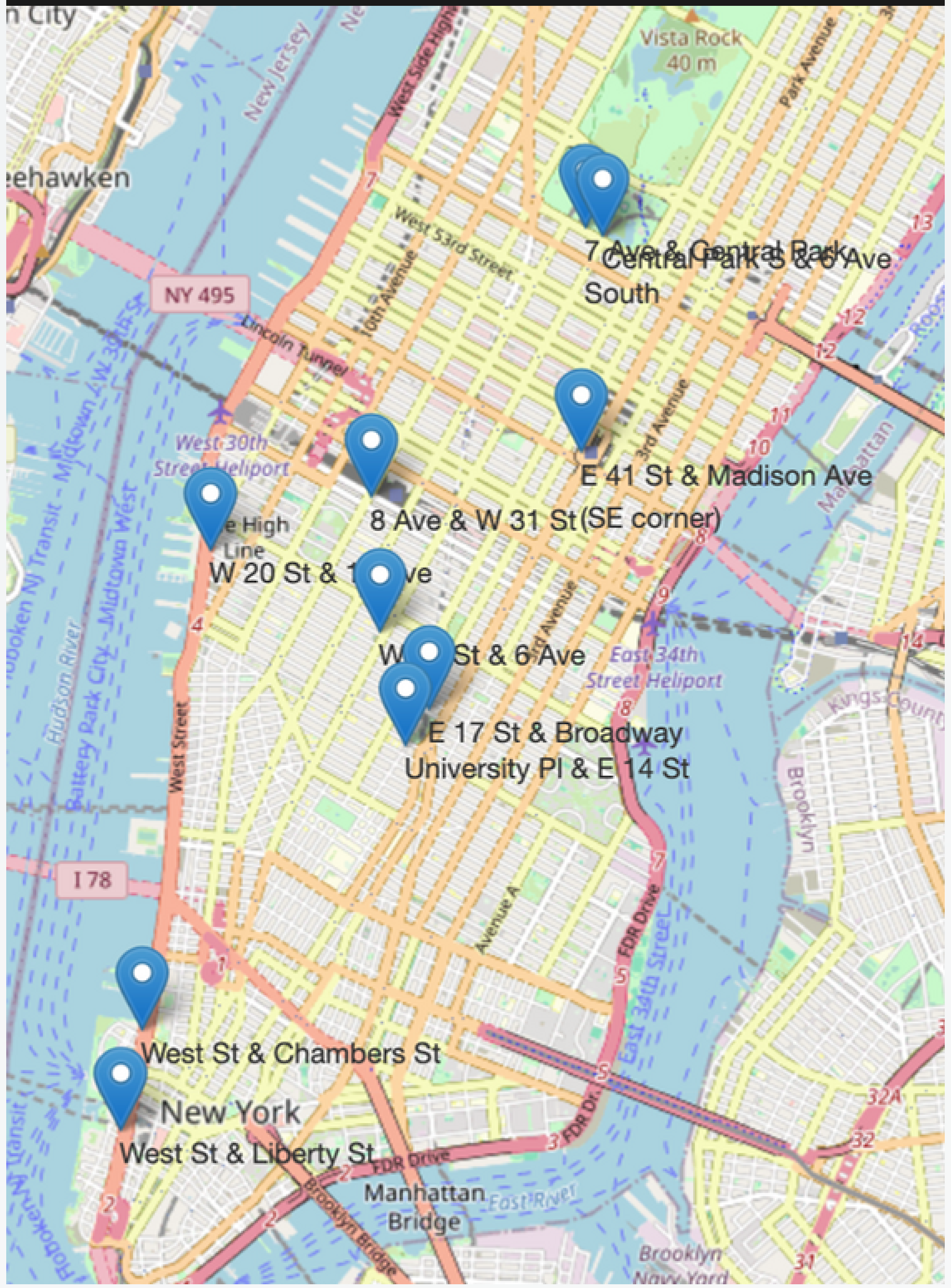
**INTERPRETING RESULTS**

- Conducting sensitivity analysis and understanding binding constraints, slack, and shadow prices.
- Reflect on the limitations and challenges of the model.

# MODEL 1

## Optimizing Bike Allocation at 10 different CitiBike Stations in the New York Metropolitan Area

### Bike Stations




### Objective Function

$$Maximize : R = \sum_{i=1}^{N} t_i \times r_i \times x_i$$

Where:

- ( R ): Total Revenue
- ( N ): Total number of stations
- ( $t_i$ ): Average time per trip at each station ( i )
- ( $r_i$ ): Average revenue per minute ( i )
- ( $x_i$ ): Predicted demand (number of bikes to be placed) at station ( i ) based on historical data

### Decision Variables

Let ( $x_i$ ) be the number of bicycles allocated to station ( i ), where ( i = 1, 2, ..., N ), where N = 10.

### Constraints

- **Bike Availability:** $\sum_{i=1}^{N} x_i \leq B$ Where ( B ) is the total number of bikes available.
- **Demand Fulfillment:** $x_i \geq d_i \quad \forall i$
- **Demand-Sensitive Ceiling:** $x_i \leq 2 \times d_i \quad \forall i$
- **Operational Capacity:** $x_i \leq 0.85 \times C_i \quad \forall i$

  Where ( $C_i$ ) is the capacity of station ( i ), adjusted for a 5% buffer for maintenance activities and ensures a 10% margin for available docks.
- **Non-Negativity:** $x_i \geq 0 \quad \forall i$

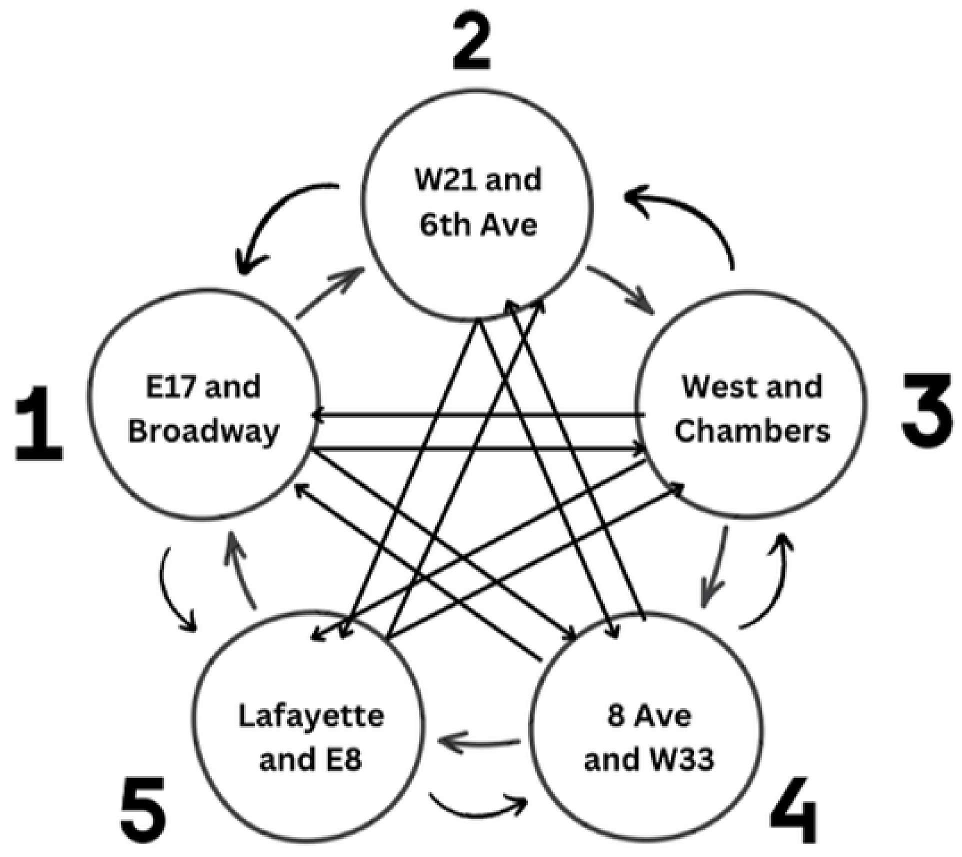
### Results

| Decision Variables | |
|---|---|
| **Station Name** | **Regular Bikes (ni)** |
| E 17 St & Broadway | 33 |
| W 21 St & 6 Ave | 50 |
| West St & Chambers St | 39 |
| 7 Ave & Central Park South | 53 |
| 8 Ave & W 31 St | 46 |
| Central Park S & 6 Ave | 43 |
| University Pl & E 14 St | 34 |
| W 20 St & 10 Ave | 40 |
| E 41 St & Madison Ave (SE corner) | 57 |
| West St & Liberty St | 37 |

# MODEL 2

## Optimizing the flow of bikes across 10 CitiBike Stations in the New York Metropolitan Area

### *Flow of Bikes*




### *Decision Variables and Constraints*

**Decision Variables**

Transit Quantities: We have identified 90 decision variables representing the number of bikes to be transported from each station
another.

Let ( $y_{ij}$ ) represent the number of bikes transported from station ( i ) to station ( j ), for all station pairs ( i, j ) where ( i, j = 1, 2, ..., N ) and ( $i \neq j$ ).

**Constraints**

**Transfer Limits:** $y_{ij} \leq T_{ij} \quad \forall i, j$ Where: ( $T_{ij}$ ) is the transfer limit between stations ( i ) and ( j ), which is 18 for short transit times and 12 for long transit times.

**Demand Satisfaction:** $\sum_{j=1}^{N} y_{ij} - \sum_{i=1}^{N} y_{ji} + n_i = D_i \quad \forall i$

Where

- ( $D_i$ ) is the projected optimal demand at station ( i )
- ( $n_i$ ) is the initial number of bikes available at station ( i )
- ( $y_{ij}$ ) represents the number of bikes transported from station i to station j
- ( $y_{ji}$ ) represents the number of bikes transported from station j to station i

**Station Capacity Compliance:** $\sum_{k=1}^{N} y_{ji} + n_i \leq C_i \quad \forall i$ Where ( $C_i$ ) is the total capacity of station ( i ), taking into account operational thresholds.

**Non-Negativity** $y_{ij} \geq 0 \quad \forall i, j$

**Objective Function**

Minimize Transit Costs: Our focus is to reduce the expenses involved in relocating bikes between stations while adhering to the forecasted demand patterns.

$$Minimize : TC = \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} c_{ij} \times y_{ij}$$

Where:

- ( TC ): Total Transit Costs
- ( N ): Total number of stations
- ( $c_{ij}$ ): Cost of transporting one bike from station ( i ) to station ( j )
- ( $y_{ij}$ ): Number of bikes transported from station ( i ) to station ( j )

# MODEL 2- RESULTS

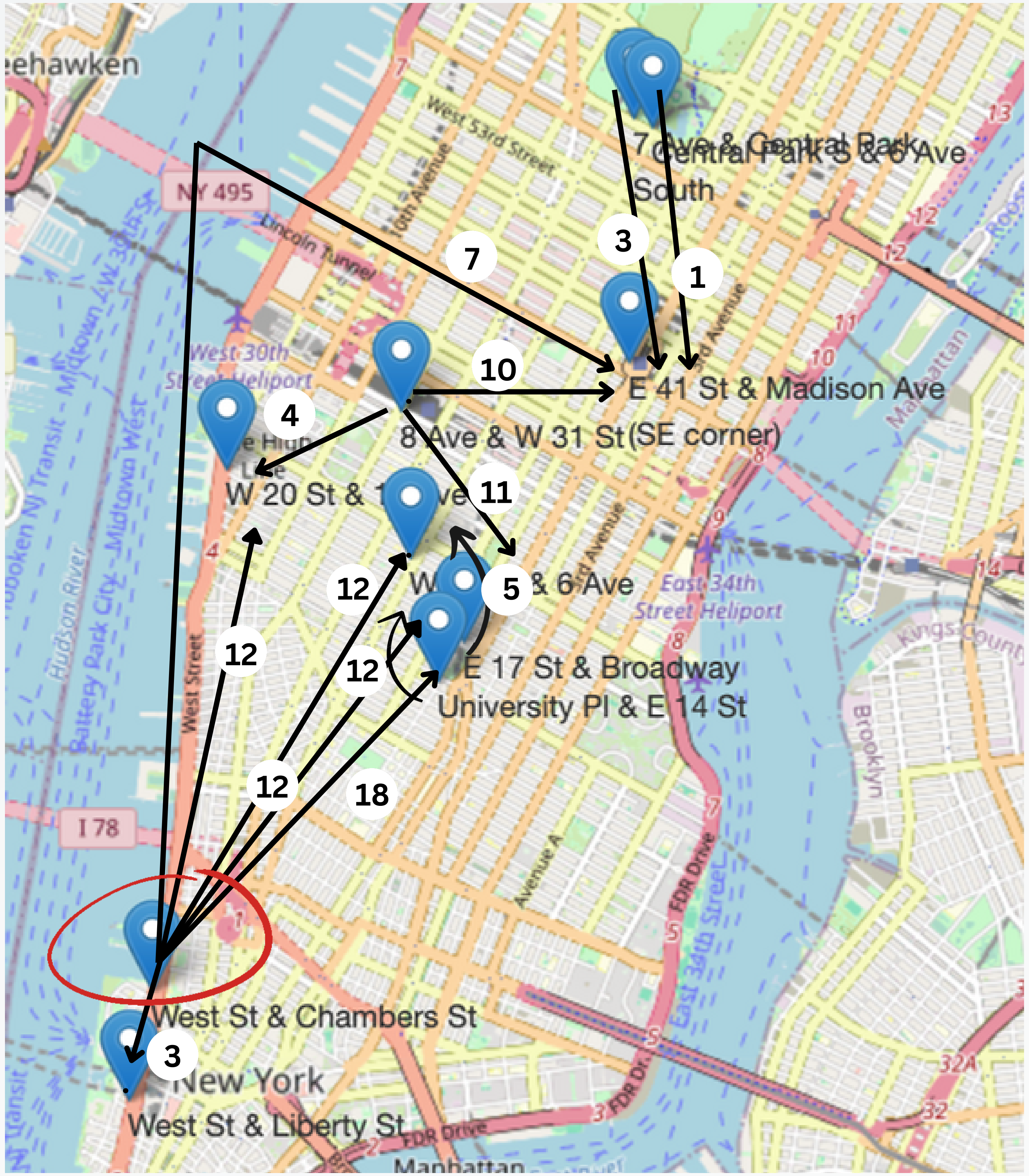
The results derived from the second model are concluded as follows:

*Inflow and Outflow*

| Stations | Net | Out | | In | Net |
|---|---|---|---|---|---|
| E 17 St & Broadway | 1 | 12 | - | 12 | 0 |
| W 21 St & 6 Ave | 2 | 0 | - | 40 | 40 |
| West St & Chambers St | 3 | 64 | - | 0 | -64 |
| 7 Ave & Central Park South | 4 | 3 | - | 0 | -3 |
| 8 Ave & W 31 St | 5 | 25 | - | 0 | -25 |
| Central Park S & 6 Ave | 6 | 1 | - | 0 | -1 |
| University Pl & E 14 St | 7 | 5 | - | 18 | 13 |
| W 20 St & 10 Ave | 8 | 0 | - | 16 | 16 |
| E 41 St & Madison Ave (SE co | 9 | 0 | - | 21 | 21 |
| West St & Liberty St | 10 | 0 | - | 3 | 3 |

*Results*

| Station Name | Historical demand | Net Flow | Optimum Bikes |
|---|---|---|---|
| E 17 St & Broadway | 33 | 0 | 33 |
| W 21 St & 6 Ave | 50 | 40 | 50 |
| West St & Chambers St | 39 | -64 | 40 |
| 7 Ave & Central Park South | 33 | 17 | 54 |
| 8 Ave & W 31 St | 46 | -25 | 46 |
| Central Park S & 6 Ave | 21 | -21 | 42 |
| University Pl & E 14 St | 34 | 13 | 34 |
| W 20 St & 10 Ave | 40 | 16 | 40 |
| E 41 St & Madison Ave (SE corner) | 57 | 21 | 57 |
| West St & Liberty St | 37 | 3 | 37 |



# SENSITIVITY ANALYSIS

**Gauging Binding and Non-Binding Constraints, Shadow prices and Slack**

## *Optimisation Model 1*

### 7 Ave & Central Park South Station

**Shadow Price:**
- Positive Shadow Price: $2.729 on Total Demand constraint.
- Impact of Increase: Raising Total Demand by 1 unit results in a $2.729 revenue increase.
- Station Revenue: 7 Ave & Central Park South has the highest revenue; not all constraints met.

### Central Park S & 6 Ave Station

**Reduced Cost:**
- Positive Reduced Cost: At Central Park S & 6 Ave indicates optimality.
- Caution Needed: Adding units may risk overutilization; sensitivity urges careful changes.

**Binding Constraints:**
- Constraints Status: Central Park S & 6 Ave constraints are binding with zero slack..
- Caution Required: Altering variables must be carefully considered to maintain feasibility.

## *Optimisation Model 2*

### Route 1 -> 2 Analysis:

- Optimal Flow: The model prescribes transporting 12 bikes, which is both sufficient and efficient.
- Cost Efficiency: The **reduced cost of zero** confirms that this route operates at peak cost-efficiency, likely benefiting from the proximity of the stations.

### Route 1 -> 3 Analysis:

- Unused Route: Currently, this route is not utilized, as indicated by a final value of zero.
- Cost Implications: The high reduced cost of $9.61 underscores the **expense sensitivity**, suggesting that additional usage would significantly increase costs due to factors such as distance or logistical barriers.

Variable Cells

| Cell | Name | Final Value | Reduced Cost | Objective Coefficient | Allowable Increase | Allowable Decrease |
|---|---|---|---|---|---|---|
| $F$6 | Decision | 12 | 0 | 0.898291693 | 0.634936932 | 0.188155821 |
| $F$7 | Decision | 0 | 9.618678663 | 4.19846637 | 1E+30 | 9.618678663 |

# PROJECT LIMITATIONS

**Maintenance and dock availability**
By reserving a fixed percentage for maintenance and empty docks, the model may either overestimate or underestimate the number of bikes and docks needed, as these needs can vary over time.

**Static Demand and Supply**
The model uses a static picture of demand and supply from Model 1 and does not account for intra-day variations in bike usage patterns.

**Operational Practicalities**
Practical issues such as the time required for loading and unloading bikes, staff availability, and the synchronization of bike transfers with other operational activities are not considered.

**Categorization of Bikes**
CitiBikes categorizes its bikes as regular and electric, each with demand and supply constraints. Due to the lack of availability of these numbers, they could not be taken into account.

**Cost Calculations**
The model assumes that the cost of moving bikes is a linear function of the number of bikes and distance, which might not reflect volume discounts, fixed costs, or economies of scale in bike logistics.

**Single Objective Focus**
In this project, we have only had the objective to optimize the flow of bikes from one station to another, and not the exact path.

# CHALLENGES AND FUTURE SCOPE

## Bike Segmentation

A difficult part of the problem was optimizing bike allocation for regular and electric bikes. We could not achieve this target due to complexity and lack of data.

## Morning Demand

This problem only optimizes for bikes to meet the morning demand. It is also assumed that not many changes are made in the bike availability post-rebalancing until the morning rush hour.

## Optimising Transportation

This project only optimizes bike flow and not the actual transportation routes. The next step would be to minimize the route's cost as well.


While our current bike optimization model focuses on morning demand and bike segmentation, we recognize the need for future improvements. Addressing challenges like seasonality and enhancing scalability are paramount for a more comprehensive solution.

As we move forward, we are committed to refining our model, incorporating emerging technologies, and expanding our data-driven approach to ensure a more dynamic and effective urban bike-sharing system.


Thank you for the ride!

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