Data-driven Design of Bike Lane Layout

Yu Tang, Qian Xie

New York University

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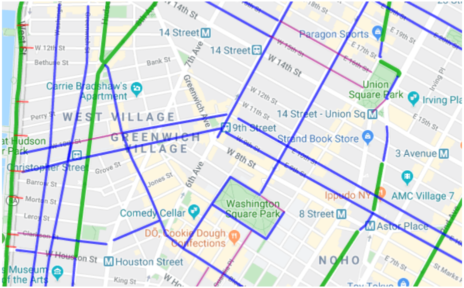
Outline

Background

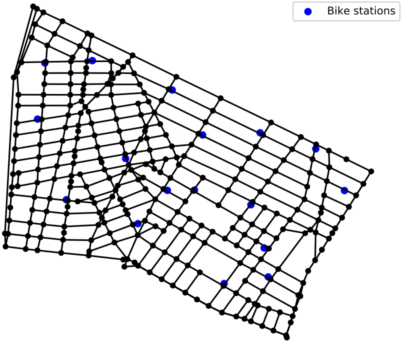
- Bike is one popular mode in New York City.
- Concern: safety, speed and capacity
- Well-planned bike lanes can cut accident risks and reduce traffic delays.
- Traditional bike lane planning is based on experience and surveys.
- In this project: data-driven and optimization (mathematical programming)

Problem Statement

- Study area: Greenwich Village in Lower Manhattan
- Benchmark: Existing bike lane layout
- Design variables: Exclusive bike lanes
- Parameters: Biking time, reduced capacity, link length, budget (total length), supply and demand at stations
- Objective: Total cost including flow cost and negative impact
- Design model: Mixed integer programming



- Traffic assignment modeling routing decision due to lack of trajectory data
- Intersections as nodes and roads as edges
- Bike stations (Trip origins and destinations) assigned to the nearest stations
- Exclusive bike lanes have larger capacity and higher free-flow speed (15km/h vs 10km/h)
- Reduced capacity defined as lane-based capacity quantifying the negative impacts of exclusive bike lanes
- Consider the budget of total length rather than construction cost



- Multicommodity Network Design [Gendron, Crainic, Frangioni 1997]
- Given: directed graph $\mathcal{G} = (\mathcal{N}, \mathcal{A})$; set of commodities to be routed $\mathcal{K}$; set of origins, destinations and transhipments for each commodity $k \in \mathcal{K}$
- Objective: minimize flow costs + γ negative impacts
- Constraints: Flow conservation; Total length budget; Flow inclusion of bike lanes and mixed lanes; Connectivity (controlled by Y)
- Variables:
  - continuous flow variables reflecting routing decisions for each link and each commodity
  - continuous flow variables for exclusive lanes and mixed lanes respectively
  - binary design variables determining whether to install an exclusive bike lane or not
  - binary design variables representing artificial exclusive bike lane that is optional depending on connectivity requirement

$$\min \sum_{(i,j)\in\mathcal{A}} (t^e_{ij}e_{ij} + t^m_{ij}m_{ij} + \gamma c_{ij}x_{ij}) \tag{1}$$

$$\text{s.t.} \sum_{j\in\mathcal{N}^+(i)} f^k_{ij} - \sum_{j\in\mathcal{N}^-(i)} f^k_{ji} = \begin{cases} o^k_i & i\in\mathcal{O}_k \\ -d^k_i & i\in\mathcal{D}_k \\ 0 & i\in\mathcal{T}_k \end{cases}, \forall k\in\mathcal{K} \tag{2}$$

$$e_{ij} \geq \sum_k f^k_{ij} - M(1-x_{ij}), \forall(i,j)\in\mathcal{A} \tag{3}$$

$$m_{ij} \geq \sum_k f^k_{ij} - Mx_{ij}, \forall(i,j)\in\mathcal{A} \tag{4}$$

$$\sum_{(i,j)\in\mathcal{A}} l_{ij}x_{ij} \leq L \tag{5}$$

$$x_{ij} \leq \sum_{\ell\in\mathcal{N}^+(j)\setminus\{i\}} (x_{j\ell}+y_{j\ell}), \forall(i,j)\in\mathcal{A} \tag{6}$$

$$x_{ij} \leq \sum_{\ell\in\mathcal{N}^-(i)\setminus\{j\}} (x_{\ell i}+y_{\ell i}), \forall(i,j)\in\mathcal{A} \tag{7}$$

$$\sum_{(i,j)\in\mathcal{A}} y_{ij} \leq Y \tag{8}$$

$$x_{ij}, y_{ij} \in \{0,1\}, e_{ij}, m_{ij}, f^k_{ij} \in \mathbb{R}_{\geq 0}, \forall(i,j)\in\mathcal{A}, k\in\mathcal{K}$$

- Trip history data
- Existing bike lane layout
- Highway Capacity Manual

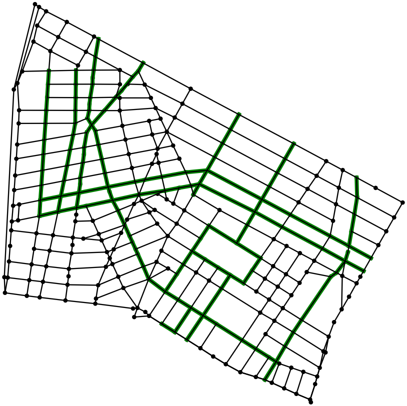
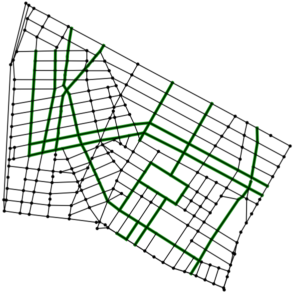
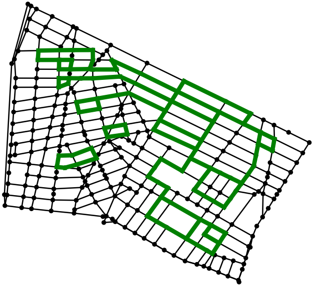


Figure: Existing bike lane layout

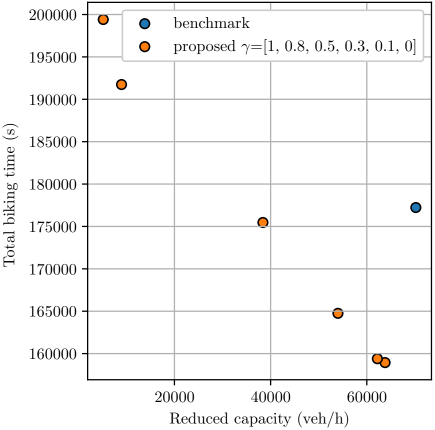
Existing bike lane layout

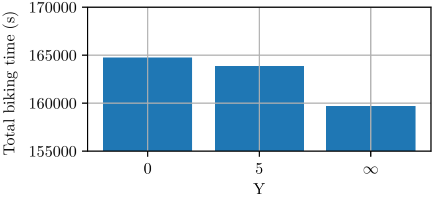


Proposed bike lane layout ($Y = 0$, $\gamma = 0.3$)

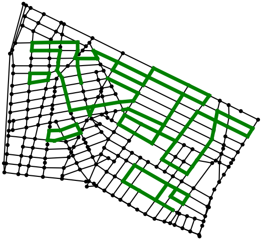


Travel time - reduced capacity

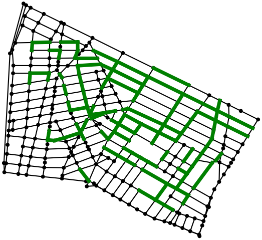




$Y = 5$



$Y = \infty$ (No connectivity requirement)



- We consider both the total biking time and negative impacts on automobiles, different weight leas to different results.
- The connectivity constraint based on real-word requirement can make an impact on total biking time but hard to ensure.
- Our proposed bike lane layout outperforms the existing one in terms of total biking time and negative impacts (reduced capacity) on automobiles.
- Multicommodity Network Design can be applied to other practical scenarios such as subway network and bus network design.

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