Analyzing the Effects of Stakeholders' Strategies in TNC System Models with Different Spatial Representations

Master's Thesis of Somakala Subbaraman

Mentoring:
Dr.-Ing Florian Dandl
Dr. Anke Ye

Motivation

- TNC services provide convenient point-to-point mobility. Cities can use this potential to improve accessibility in poorly connected areas.
- Various spatial models have been proposed in literature, but there lacks an analysis of the implication of choosing different spatial representations

Research Question

- What impact does spatial aggregation level have on TNC equilibrium outcomes and the resulting policy recommendations?
- How do different formulations of TNC optimization problems affect the equity and efficiency of the resulting TNC equilibrium?
- To what extent does using a zone-level evaluation differ from using a disaggregated evaluation of the performance of policy suggestions?

TNC Equilibrium Model

Demand:
Logit Mode Choice, including captive TNC users

$$Q_{i,j} = f_1(W_i^c) = (1 - p_{cap})\, Q_{i,j}^0 \cdot \frac{e^{U_{i,j}^T}}{e^{U_{i,j}^T} + e^{U_{i,j}^P}} + p_{cap} \cdot Q_{i,j}^0 \qquad \forall \quad (i,j) \in Z^2$$

Matching:
Intra-zone Batch Matching with Infinite Matching Radius and Supply Dominance

$$W_i^v = f_2(W_i^c, \mathbf{Q_{i,*}}) = \frac{A_i \left(\frac{\zeta}{2v(W_i^c - \tau/2)} \right)^2}{\sum_{k \in Z} Q_{i,k}} - \frac{\tau}{2} \qquad \forall \quad i \in Z$$

Repositioning:
Logit Location Choice, maximizing expected net revenue

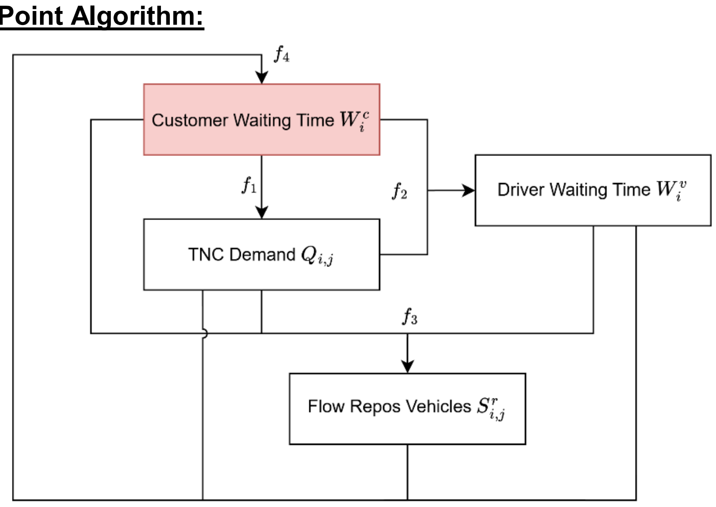
$$S_{i,j}^r = f_3(\mathbf{W^c}, \mathbf{Q}, \mathbf{W^v}) = \frac{e^{\theta U_{i,j}^v}}{\sum_{k \in Z} e^{\theta U_{i,k}^v}} \cdot \sum_{k \in Z} Q_{k,i} \qquad \forall \quad (i,j) \in Z^2$$

Supply:
Fleet Conservation within a zone

$$W_i^c = f_4(W_i^v, \mathbf{Q}, \mathbf{S^r_{i,*}})$$

$$= \frac{N_{fleet,i} - \sum_{j \in Z} S_{i,j}^r \cdot t_{i,j}^{repos} - \sum_{j \in Z} Q_{i,j} \cdot t_{i,j}^T}{\sum_{j \in Z} Q_{i,j}} - W_i^v + \frac{\tau}{2} \qquad \forall \quad i \in Z$$

Fixed Point Algorithm:



Optimization Problem

Government assigns subsidy $\gamma_{i,j}$ for TNC trips given a budget B

Average Experienced Utility
$$\bar{U}_{i,j} = \frac{Q_{i,j} U_{i,j}^T + (Q_{i,j}^0 - Q_{i,j}) U_{i,j}^P}{Q_{i,j}^0}$$

Goal 1: Efficiency

Mean Ū across ODs

$$\max_{\gamma} \sum_{(i,j) \in Z^2} \bar{U}_{i,j} \cdot Q_{i,j}^0$$
$$s.t. \sum_{(i,j) \in Z^2} \gamma_{i,j} \cdot Q_{i,j} \leq B,$$
$$\mathbf{W^c} = F(\mathbf{W^c})$$

Goal 2: Fairness

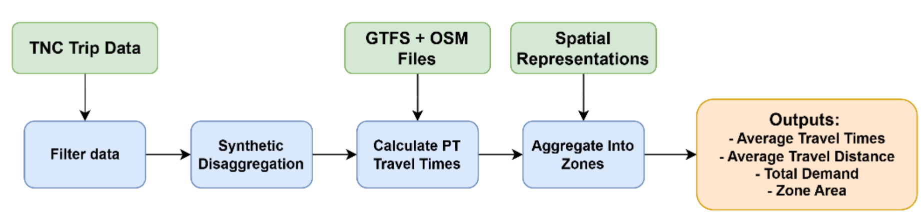
Variance of Ū across ODs

$$\max_{\gamma} \; -1 \cdot \sum_{(i,j) \in Z^2} \left(\bar{U}_{i,j} - \sum_{(i,j) \in Z^2} \frac{\bar{U}_{i,j}}{n_{OD}} \right)^2$$
$$s.t. \sum_{(i,j) \in Z^2} \gamma_{i,j} \cdot Q_{i,j} \leq B,$$
$$\mathbf{W^c} = F(\mathbf{W^c})$$

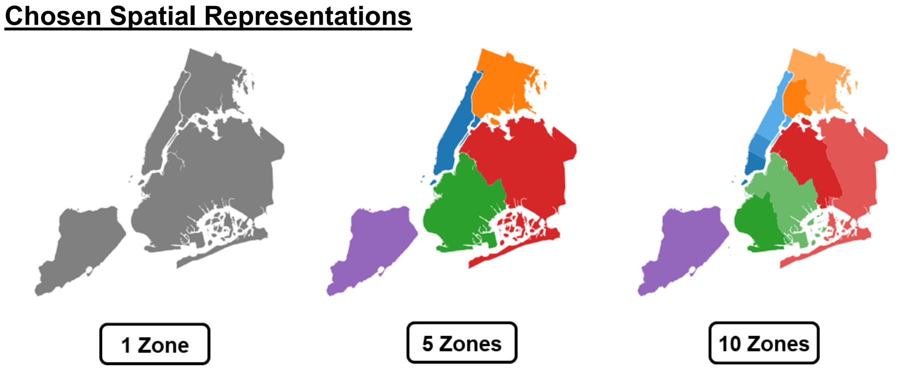
- ADMM Based Implementation where subsidies for each OD link are iteratively optimized using a grid search

Case Study: New York City

Data Preprocessing



Chosen Spatial Representations



Results

Equilibrium in Status Quo

- When using finer spatial representations, a larger proportion of the fleet is repositioning and not available for matching. Thus, the available supply decreases leading to lower driver waiting times and higher customer waiting times.
- At finer spatial representations, the assumption of a supply dominant market does not hold

Subsidy Optimization

- The efficiency optimization allocates subsidies in a way to induce a favourable mode change, while the fairness optimization only subsidizes trips with utilities under the mean
- Zones pairs with more homogenous utilities show higher congruence between trip level and zone-level metrics