Improving Travel Mobility by Integrating Transit and Ride-Sourcing Services

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1. Background & Introduction
2. Methodology
3. Experimental Results
4. Conclusions
1. Background & Introduction

Background

- Transit and TNC partnership
- First/Last mile problem
1. Background & Introduction

Background

- Transit and TNC partnership
- First/Last mile problem
Integration of transit and TNC services
Introduction (Cont.)

- Mutual effects, closed loop

- Research question: What properties does this equilibrium problem have?
- Research question: How can both riders’ and drivers’ benefits can be jointly maximized at equilibrium?
Introduction (Cont.)

- Mutual effects, closed loop

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- Research question: How can both riders' and drivers' benefits be jointly maximized at equilibrium?
Introduction (Cont.)

- Mutual effects, closed loop

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- Research question: How can both riders’ and drivers’ benefits be jointly maximized at equilibrium?
Component functions

\[ N_r = V_r - \sum_{s \in Z} D_{rs} R^{t R} \quad \forall r \in Z \quad (1) \]

\[ W_r^R = W_r^R(N_r) \quad \forall r \in Z \quad (2) \]

\[ F_{rs} R = (1 + S_r(N_r))(\alpha t_{rs} + \beta L_{rs}) + B \quad \forall rs \in Z^2 \quad (3) \]

\[ D_{rs} R = D_{rs} R(F_{rs} R, W_r R) = D_{rs} R(F_{rs} R(N_r), W_r R(N_r)) \quad \forall rs \in Z^2 \quad (4) \]

\[ P_r = P_r(F_{rs} R, D_{rs} R, V_r) = \eta \sum_{s \in Z} F_{rs} R D_{rs} R \frac{V_r}{V_r} \quad \forall r \in Z \quad (5) \]

\[ D_{rs} R = D_{rs} R(F_{rs} R(\sum_{s \in Z} D_{rs} R), W_r R(\sum_{s \in Z} D_{rs} R)) \quad \forall rs \in Z^2 \quad (6) \]
2. Methodology

Mathematical Models

**SUE Modal Split**

$$\min \sum_{ijA} \int_0^{x_{ij}} t_{ij}(\omega) \, d\omega + \frac{1}{\theta} \sum_{rs \in \mathbb{Z}^2} \sum_{\pi \in \Pi_{rs}} h^\pi \ln(h^\pi)$$  

S.t.

$$\sum_{\pi \in \Pi_{rs}} h^\pi = d^{rs}_T$$  

$$h^\pi \geq 0$$  

$$x_{ij} = \sum_{\pi \in \Pi_r} h^\pi \delta^\pi_{ij}$$  

$$\forall i,j \in A$$  


**Vehicle Assignment**

$$\min \sum_{r \in \mathbb{Z}} \int_0^{V_r} -P_r(\omega) \, d\omega$$

S.t.

$$\sum_r V_r = V$$  

$$V_r \geq 0$$  

$$\forall r \in \mathbb{Z}$$
2. Methodology

Demand assignment

Figure: Demand graph representation - Modal split
2. Methodology

TNC vehicle assignment

Figure: TNC vehicle assignment model
### Experiment Setup

- Travel to the MSP airport using the Blue Line as the main transit mode;
- Around 1000 zones analyzed;
- 11 instances with different fleet size:

<table>
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<th>#</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>$V$</td>
<td>13805</td>
<td>6902</td>
<td>4601</td>
<td>3451</td>
<td>2761</td>
<td>2300</td>
<td>1972</td>
<td>1752</td>
<td>1533</td>
<td>1380</td>
<td>6902</td>
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<td>(D/2)</td>
<td>(D/3)</td>
<td>(D/4)</td>
<td>(D/5)</td>
<td>(D/6)</td>
<td>(D/7)</td>
<td>(D/8)</td>
<td>(D/9)</td>
<td>(D/10)</td>
<td>(D/20)</td>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>$\theta$</td>
<td>Distribution parameter of logit model</td>
<td>0.01</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Time-based fare coefficient</td>
<td>0.26</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Distance-based fare coefficient</td>
<td>0.85</td>
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<td>$\gamma$</td>
<td>Waiting time function coefficient</td>
<td>16.5</td>
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<tr>
<td>$\lambda$</td>
<td>Surge pricing coefficient</td>
<td>5.5</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Payoff reduction coefficient</td>
<td>0.5</td>
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**Table:** Parameter settings
3. Experimental Results

Convergence trajectory

Convergence trajectory for expected payoff

Convergence trajectory for TNC demand
Optimal Fleet Size

![Graph showing the relationship between expected total payoff and average payoff across zones with respect to the number of drivers (fleet size).](image-url)
Decreasing Rate of Demand
TNC service waiting time

![Graph showing TNC service waiting time vs. number of drivers (fleet size). The graph illustrates the decrease in average waiting time and demand/supply ratio with an increase in the number of drivers.]
Served Zones
3. Experimental Results

Served Zones (Cont.)

\[ V = 690 \left( \frac{D}{20} \right) \]
Served Zones (Cont.)

\[ V = 1380\left(\frac{D}{10}\right) \]
Served Zones (Cont.)

\[ V = 2761 \left( \frac{D}{5} \right) \]
3. Experimental Results

### Time-based Fare Coefficient Sensitivity Analysis

**Uber:**
\[ F_{rs}^R = (1 + S_r(N_r))(\alpha t_{rs}^R + \beta L_{rs}^R) + B \]

<table>
<thead>
<tr>
<th>Time-based Fare Coefficient</th>
<th>TNC Demand</th>
<th>TNC Split</th>
<th>D/V</th>
<th>Total Payoff ($)</th>
<th>Average Fare ($)</th>
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<tbody>
<tr>
<td>0.09 (\times) (\frac{1}{3})</td>
<td>5503</td>
<td>39.73%</td>
<td>2.39</td>
<td>144875</td>
<td>22.0</td>
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<tr>
<td>0.26 (base case)</td>
<td>5359</td>
<td>38.69%</td>
<td>2.33</td>
<td>160955</td>
<td>24.6</td>
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<tr>
<td>0.78 (\times) 3</td>
<td>4818</td>
<td>34.79%</td>
<td>2.09</td>
<td>182185</td>
<td>32.5</td>
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<td>2.60 (\times) 10</td>
<td>2856</td>
<td>20.62%</td>
<td>1.24</td>
<td>138401</td>
<td>50.8</td>
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**Table:** Time-based Fare Coefficient Sensitivity Analysis
Conclusions

▶ There exist an optimal fleet size at equilibrium that maximizes the drivers’ payoff;
▶ TNC demand exhibits decreasing returns to scale property;
▶ Increasing time and distance fare coefficient reduces demand, but total payoff can increase.
Thanks!