Assessing Transit Oriented Development Strategies with a New Combined Modal Split and Traffic Assignment Model

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Motivation

- Public transportation can mitigate congestion and alleviate air pollution.
- Transit oriented development (TOD) will promote public transportation.
- Traditional planning models fail to consider users’ captivity in mode choice.
- Route overlapping is one of the major concerns in route choice models.

This study aims at developing a new combined modal split and traffic assignment (CMSTA) model to quantitatively assess TOD strategies.
TOD’s Impacts on Travel Behavior

- TOD boosts transit ridership.
- TOD induces higher transit mode share.
- TOD reduces travelers’ trips by autos.
Transit Captivity

• Auto ownership level has huge impact on travelers’ mode choice behavior in TODs.

• Travelers with no vehicle available are more likely to commute by transit.

• TOD residents tend to own fewer cars.
Evaluation of TOD Strategies

• Empirical study of travel survey data
  • Statistical analysis/modeling of travel survey data
  • Station level evaluation

• Transportation network modeling
  • Overall impacts of TODs at network/regional level
Dogit Model

• Choice model
  • Choice among specific pairs of alternatives to be consistent with the independence from irrelevant alternatives (IIA) property
  • Allow choice among other pairs not to possess the IIA property.

• Can be used to consider user captivity
  • Mode choice
  • Destination choice
  • Customer loyalty in product shopping behaviors
Dogit Model

- Mode choice probability

\[
P_{ij}^m = \frac{\exp(V_{ij}^m) + \eta_{ij}^m \sum_{n \in M_y} \exp(V_{ij}^n)}{\left(1 + \sum_{n \in M_y} \eta_{ij}^n \right) \sum_{n \in M_y} \exp(V_{ij}^n)}
\]

where \( P_{ij}^m \) = probability that an individual will select travel mode \( m \) between O-D pair \( ij \).

\( V_{ij}^m \) = deterministic component of the utility of travel mode \( m \) between O-D pair \( ij \).

\( \eta_{ij}^m \) = captivity parameter related to mode choice \( m \), \( \eta_{ij}^m \geq 0, \forall m \in M_y \).
Dogit Model

- **Mode choice probability**

\[
P_{ij}^m = \frac{\eta_{ij}^m}{1 + \sum_{p \in M_i} \eta_{ij}^p} + \frac{1}{1 + \sum_{p \in M_i} \eta_{ij}^p} \cdot \frac{\exp(V_{ij}^m)}{\sum_{p \in M_i} \exp(V_{ij}^p)}
\]

\[
= \eta_{ij}^m \vartheta_{ij} + \vartheta_{ij} \kappa_{ij}^m
\]

where \( \kappa_{ij}^m = \exp(V_{ij}^m) / \sum_{p \in M_i} \exp(V_{ij}^p) \), \( \forall m \in M_i, ij \in IJ \) and \( \vartheta_{ij} = 1 / (1 + \sum_{p \in M_i} \eta_{ij}^p) \), \( \forall ij \in IJ \)

- **Probability ratio between two alternatives**

\[
\frac{P_{ij}^m}{P_{ij}^n} = \frac{\eta_{ij}^m \vartheta_{ij} + \vartheta_{ij} \kappa_{ij}^m}{\eta_{ij}^n \vartheta_{ij} + \vartheta_{ij} \kappa_{ij}^n} = \frac{\eta_{ij}^m + \kappa_{ij}^m}{\eta_{ij}^n + \kappa_{ij}^n}
\]

IIA holds only when \( \eta_{ij}^m \) and \( \eta_{ij}^n \) both be zero
Dogit-PSL Model

\[
\min Z = Z_1 + Z_2 + Z_3 + Z_4 + Z_5 + Z_6
\]

**Logit SUE**

\[
\sum_{m \in M_v} \sum_{a \in A} \int_0^{
u_{ma}} h_{ma}(\omega) d\omega + \frac{1}{\theta} \sum_{ij \in IJ} \sum_{m \in M_v} \sum_{r \in R_i^m} f_{ij}^{mr} \left( \ln f_{ij}^{mr} - 1 \right)
\]

Entropy related to overlapping choices

**Entropy related to overlapping choices**

\[
- \frac{1}{\theta} \sum_{ij \in IJ} \sum_{m \in M_v} \sum_{r \in R_i^m} f_{ij}^{mr} \ln \omega_{ij}^{mr} + \frac{1}{\gamma} \sum_{ij \in IJ} \sum_{m \in M_v} \left[ \left( q_{ij}^m - \theta q_{ij}^m \eta_{ij}^m q_{ij} \right) \ln \left( q_{ij}^m - \theta q_{ij}^m \eta_{ij}^m q_{ij} \right) \right]
\]

Flow conservation constraints

\[
\sum_{m \in M_v} q_{ij}^m = q_{ij}, \quad \forall ij \in IJ,
\]

\[
\sum_{r \in R_i^m} f_{ij}^{mr} = q_{ij}^m, \quad \forall m \in M_v, ij \in IJ,
\]

\[
q_{ij}^m \geq 0, \quad \forall m \in M_v, ij \in IJ,
\]

\[
f_{ij}^{mr} \geq 0, \quad \forall r \in R_i^m, m \in M_v, ij \in IJ,
\]
Numerical Results

- Nyuyen and Dupius Network
  - TOD improves transit service
  - Transit travel time decreases by 10%, 20% and 50%
Numerical Results

FIGURE 2 Modal Splits in Different Scenarios for the MNL-PSL and Dogit-PSL Models
Numerical Results

FIGURE 3 Network Modal Splits in the MNL-PSL and the Dogit-PSL Models under Different Scenarios

Ignorance of captive users tend to overestimate the impact of TOD strategy on the mode split results
Table 3. Mode and network VMTs under different transit FFTT improvement scenarios

<table>
<thead>
<tr>
<th>Mode</th>
<th>MNL-PSL</th>
<th></th>
<th></th>
<th></th>
<th>Dogit-PSL</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base case</td>
<td>10%</td>
<td>20%</td>
<td>50%</td>
<td>Base case</td>
<td>10%</td>
<td>20%</td>
<td>50%</td>
</tr>
<tr>
<td>Car</td>
<td>11,649.5</td>
<td>10,763.8</td>
<td>6,373.9</td>
<td>6,373.9</td>
<td>11,992.6</td>
<td>11,318.9</td>
<td>10,470.7</td>
<td>6,141.6</td>
</tr>
<tr>
<td></td>
<td>(-0.059)*</td>
<td>(-0.130)</td>
<td>(-0.485)</td>
<td></td>
<td></td>
<td>(-0.056)</td>
<td>(-0.127)</td>
<td>(-0.488)</td>
</tr>
<tr>
<td>Transit</td>
<td>1,089.3</td>
<td>1,269.4</td>
<td>1,930</td>
<td></td>
<td>993.8</td>
<td>1149.0</td>
<td>1,318.0</td>
<td>1,960.5</td>
</tr>
<tr>
<td></td>
<td>(+0.188)</td>
<td>(+0.384)</td>
<td>(+1.105)</td>
<td></td>
<td></td>
<td>(+0.156)</td>
<td>(+0.326)</td>
<td>(+0.97)</td>
</tr>
<tr>
<td>Bike</td>
<td>3,561.6</td>
<td>2,734.8</td>
<td>891.4</td>
<td></td>
<td>4,147.9</td>
<td>3341.7</td>
<td>2,581.3</td>
<td>844.7</td>
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<td></td>
<td>(-0.205)</td>
<td>(-0.389)</td>
<td>(-0.801)</td>
<td></td>
<td></td>
<td>(-0.194)</td>
<td>(-0.378)</td>
<td>(-0.796)</td>
</tr>
<tr>
<td>Sum</td>
<td>12,024.1</td>
<td>10,716.7</td>
<td>6,855.5</td>
<td></td>
<td>17,134.2</td>
<td>15,809.7</td>
<td>14,370.1</td>
<td>8,946.8</td>
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<tr>
<td></td>
<td>(-0.091)</td>
<td>(-0.190)</td>
<td>(-0.482)</td>
<td></td>
<td></td>
<td>(-0.077)</td>
<td>(-0.161)</td>
<td>(-0.478)</td>
</tr>
</tbody>
</table>

* This cell means VMT for car decreases 5.9 percent compared with the base case after implementing the TOD strategy.

Ignorance of captive users tend to overestimate the impact of TOD strategy on the increase of transit VMTs
Concluding Remarks

• A new mathematical programming formulation for the CMSTA problem is proposed.

• Captive travel behavior in mode choice and route overlapping in route choice are explicitly considered.

• Numerical examples show that ignoring mode captivity can lead to biased results in evaluating the impacts of TOD strategies.
Thank You!