Passenger satisfaction maximization within a demand-based optimization framework

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16/05/2019
Introduction

Methodology

Proof of concept

Conclusions and future work
Motivation

- Negative externalities
- Revenue recycling
- Impact on the social welfare

- Demand-based optimization
- Operator’s point of view
- Profit maximization (MILP)
Passenger satisfaction

- Typically used to evaluate existing services and hypothetical scenarios
- Less often considered during the supply decision making
- Two relevant works with discrete choice models:
  - Atasoy et al. (2015): Flexible Mobility on Demand (FMOD) system
  - Robenek et al. (2016): train timetabling problem
  - In both cases, passenger satisfaction defined as the consumer surplus
- Here: measured as the **expected maximum utility** (EMU)
Revenue recycling allows to ameliorate adverse equity impacts

Disaggregate demand provides valuable insight into road pricing and public transportation (PT) management

However, restrictions on the elasticities and substitution patterns:
  - Huang (2002): elastic demand but identical commuters
  - Basso and Jara-Díaz (2012): logit model with only attributes

Here: revenue recycling with highway toll and PT fare as supply decisions for any choice model
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3. Proof of concept
4. Conclusions and future work
Methodology

Choice model linearization

\[ U_{in} = V_{in} + \varepsilon_{in} \]

\[ U_{inr} = V_{in} + \xi_{inr} \]

draw distribution (R)

\[ U_{nr} = \max_i U_{inr} \]

\[ U_{nr} \leq U_{inr} \leq U_{inr} + M_{inr}(1 - w_{inr}) \]

Utility function:

\[ U_{inr} = \beta_{in} p_{in} + g_{in}(x_{in}) + \xi_{inr} \]

Choice variables:

\[ w_{inr} = 1 \text{ if } i \text{ chosen by } n \text{ in draw } r, \ 0 \text{ otherwise} \]

Demand for alternative \( i \):

\[ D_i = \frac{1}{R} \sum_r \sum_n w_{inr} \]
Expected maximum utility

- It represents the benefit obtained by an individual from their choice
- Logit: EMU is equivalent to the consumer surplus up to a constant
- The same applies to Multivariate Extreme Value (MEV) models
Methodology

Passenger satisfaction maximization

\[
\max \sum_n E[\max_i U_{in}] \quad \text{linear choice model} \quad \max \frac{1}{R} \sum_n \sum_r U_{nr}
\]

- Approximation to the EMU
- \( E[\max_i U_{in}] \approx \frac{1}{R} \sum_r E[\max_i U_{inr}] = \frac{1}{R} \sum_r U_{nr} \) for one individual
- Passenger satisfaction = aggregation of the approximated EMU
Revenue recycling strategy (1)

- $N$ individuals performing a trip in a given time horizon
- $C$: car and PT (and possibly other modes)
- One transportation authority that decides on:
  - highway toll (to be implemented): $p_{\text{car},n}$
  - PT fare: $p_{\text{PT},n}$
- These decisions are **endogenous variables** of the formulation
Revenue recycling strategy (2)

- Investment \( I \) does not exceed the available budget \( B \)

- Investment: \( I^{\text{car}} + I^{\text{PT}} \)
  - \( I^{\text{car}} \): fixed costs \( F^{\text{car}} \) and cost per transaction \( c^{\text{car}} \)
  - \( I^{\text{PT}} \): fixed costs \( F^{\text{PT}} \)

\[
I = F^{\text{car}} + \frac{1}{R} c^{\text{car}} \sum_n \sum_r w_{\text{car},n,r} + F^{\text{PT}}
\]

- Budget: initial budget \( B^0 \) + collected revenues

\[
B = B^0 + \frac{1}{R} \sum_n \sum_r \left[ \eta_{\text{car},n,r} p_{\text{car},n} w_{\text{car},n,r} + \eta_{\text{PT},n,r} p_{\text{PT},n} w_{\text{PT},n,r} \right]
\]
### Methodology

#### Passenger satisfaction maximization with revenue recycling

**Objective Function**

$$ \max \frac{1}{R} \sum_n \sum_r U_{nr} $$

**Utility**

$$ U_{inr} = \beta_{in} p_{in} + g_{in}(x_{in}) + \xi_{inr} $$

**Linearizing Constraints**

- Only one alternative can be chosen
- Linearization of the variable $\eta_{inr} = p_{in} w_{inr}$

```
F_{car} + \frac{1}{R} c_{car} \sum_n \sum_r w_{car,n,r} + F^{PT} \leq B^0 + \frac{1}{R} \sum_i \sum_n \sum_r \eta_{inr}
```
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Motivation

- Case study to illustrate the logic of the formulation
- Definition of a scenario inspired in reality
- Estimation of a choice model (logit)
- Creation of a synthetic sample to run the MILP model
- Benchmark: initial vs optimized situation
Scenario (1)

- Lausanne-Morges region
- 66.6% of the trips by car in the region use the highway
- Simplification: we only consider the city centers
Scenario (2)

- Trips from the city center of Morges to the city center of Lausanne
- Car (highway), PT (railway) and slow modes (SM, only bicycle)
- Departing time horizon: morning peak hour (07:00-07:59)
- Purpose of the trip: going to work
- Data not available for this scenario:
  - existing RP data (Switzerland) to calibrate the choice model
  - creation of synthetic data to run the optimization model
Optima case study

- Project conducted by LASUR, TRANSP-OR and CEAT (EPFL)
- RP survey conducted between 2009 and 2010 by CarPostal
- 1124 completed surveys: trip information and socioeconomic data
Choice model

- Sample of 446 individuals (excluding missing values + rural + leisure)
- Time and cost for car and PT, distance for SM
- Income as the only socioeconomic variable (interacted with cost)

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>PT</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ASC_{\text{Car}}$</td>
<td>0.958</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$ASC_{\text{PT}}$</td>
<td>1.57</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$\beta_{\text{Time}}$</td>
<td>-0.016</td>
<td>TimeCar$_n$</td>
<td>TimePT$_n$</td>
</tr>
<tr>
<td>$\beta_{\text{CostLow}}$</td>
<td>-0.143</td>
<td>CostCar$_n$ · LowIncome$_n$</td>
<td>CostPT$_n$ · LowIncome$_n$</td>
</tr>
<tr>
<td>$\beta_{\text{CostMed}}$</td>
<td>-0.198</td>
<td>CostCar$_n$ · MedIncome$_n$</td>
<td>CostPT$_n$ · MedIncome$_n$</td>
</tr>
<tr>
<td>$\beta_{\text{CostHigh}}$</td>
<td>-0.105</td>
<td>CostCar$_n$ · HighIncome$_n$</td>
<td>CostPT$_n$ · HighIncome$_n$</td>
</tr>
<tr>
<td>$\beta_{\text{Distance}}$</td>
<td>-0.125</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Synthetic sample (1)

Distance between O and D divided in three parts: $d_{1n} + d + d_{2n}$
- Distance within Morges ($d_{1n}$): [0.1, 1.5] km
- Distance within Lausanne ($d_{2n}$): [0.2, 3] km
- Distance connecting the zones ($d$): 12 km
Synthetic sample (2)

- Generation of $N = 50$ individuals to run the optimization problem
- Morning peak hour: considered for speed assumptions
- $\text{TimeCar}_n$:
  - $d_1$ and $d_2$: 15 km/h
  - $d$: [45, 70] km/h
- $\text{TimePT}_n$:
  - $d_1$ and $d_2$: 5 km/h if $d_j < 1.5$ km and 15 km/h if $d_2 > 1.5$ km
  - waiting time: [0,8] min (8 = expected waiting time)
  - in-vehicle time: 13.8 min (weighted average current in-vehicle times)
- $\text{Distance}_n = d_{1n} + d + d_{2n}$
Proof of concept

Benchmark (1)

- PT fare: 3.27 CHF (Mobilis monthly ticket)
- Car toll: 0 CHF
- Car cost: 0.27 CHF/km

\[ B^0 = 0 \text{ CHF} \]
\[ F^{\text{car}} = 54.53 \text{ CHF} \]
\[ c^{\text{car}} = 0.44 \text{ CHF} \]
\[ F^{\text{PT}} = 22.96 \text{ CHF} \]

- Variable car cost: gas, maintenance and repairs, etc. (TCS)
- Fixed costs: cost per person and kilometer (ARE)
### Benchmark (2)

<table>
<thead>
<tr>
<th>Situation</th>
<th>Fare</th>
<th>Toll</th>
<th>( D_{PT} ) (%)</th>
<th>( D_{car} ) (%)</th>
<th>( D_{SM} ) (%)</th>
<th>EMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>3.27</td>
<td>0</td>
<td>57.50</td>
<td>36.22</td>
<td>6.28</td>
<td>156.27</td>
</tr>
<tr>
<td>Optimized</td>
<td>1.56</td>
<td>2.30</td>
<td>71.80</td>
<td>23.02</td>
<td>5.18</td>
<td>163.77</td>
</tr>
</tbody>
</table>

- Illustrative values based on the tested scenario
- Modal shift towards PT
- Decrease of the fare associated with PT
- Increase of the passenger satisfaction (EMU)
Conclusions and future work
Conclusions

- Linear framework to maximize passenger satisfaction
- Any decision variable related to revenue recycling can be included
- Flexible approach: integrate different policies, evaluate specific goals
- Proof of concept to illustrate the logic of the formulation
Conclusions and future work

Future work

- Incorporate frequency of PT as a decision variable (capacity?)
- Additional decisions: to set the toll or not
- Generate different scenarios to test other features: congestion effect
- Test the formulation with an ICLV model from the literature in a real case study
Questions?

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Conclusions and future work

Bibliography


