Passenger satisfaction maximization within a demand-based optimization framework

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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

- 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

Choice model linearization

$$U_{in} = V_{in} + \varepsilon_{in} \xrightarrow{\text{draw distribution } (R)} U_{inr} = V_{in} + \xi_{inr}$$

$$U_{nr} = \max_i U_{inr} \xrightarrow{\text{linearization}} \begin{array}{l} U_{inr} \leq U_{nr} \\ U_{nr} \leq U_{inr} + M_{inr}(1 - w_{inr}) \end{array}$$

- Utility function: $U_{inr} = \overbrace{\beta_{in} p_{in} + g_{in}(x_{in})}^{V_{in}} + \xi_{inr}$
- Choice variables: $w_{inr} = 1$ if i chosen by n in draw r, 0 otherwise
- Demand for alternative i: $D_i = \frac{1}{R} \sum_r \sum_n w_{inr}$

Expected maximum utility

$$\mathbf{E}\left[\max_i U_{in}\right]$$

- 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

Passenger satisfaction maximization

$$\max \sum_n \mathbf{E}\left[\max_i U_{in}\right] \xrightarrow{\text{linear choice model}} \max \frac{1}{R} \sum_n \sum_r U_{nr}$$

- Approximation to the EMU
- $\mathbf{E}\left[\max_i U_{in}\right] \simeq \frac{1}{R} \sum_r \mathbf{E}\left[\max_i U_{inr}\right] = \frac{1}{R} \sum_r U_{nr}$ for one individual
- Passenger satisfaction = aggregation of the approximated EMU

Revenue recycling strategy (1)

- N individuals performing a trip in a given time horizon
- $\mathscr{C}$: 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)

$$I \leq B$$

- Investment (I) does not exceed the available budget (B)
- Investment: $I^{\text{car}} + I^{\text{PT}}$
  - I^{car}: fixed costs (F^{car}) and cost per transaction (c^{car})
  - I^{PT}: fixed costs (F^{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

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

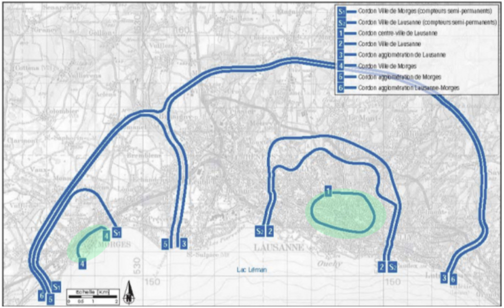
Passenger satisfaction maximization with revenue recycling

obj. fun.	$\max \frac{1}{R}\sum_n \sum_r U_{nr}$
utility	$U_{inr} = \beta_{in} p_{in} + g_{in}(x_{in}) + \xi_{inr}$
highest utility	linearizing constraints
choice	only one alternative can be chosen
price	linearization of the variable $\eta_{inr} = p_{in} w_{inr}$
budget	$F^{\text{car}} + \frac{1}{R} c^{\text{car}} \sum_n \sum_r w_{\text{car},n,r} + F^{\text{PT}} \leq B^0 + \frac{1}{R} \sum_i \sum_n \sum_r \eta_{inr}$

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

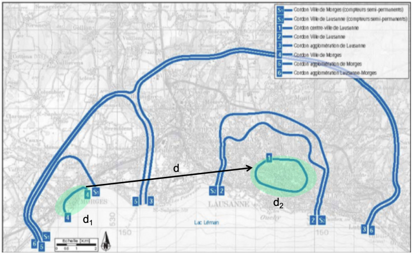
- Project conducted by LASUR, TRANSP-OR and CEAT (EPFL)
- RP survey conducted between 2009 and 2010 by CarPostal
- 1124 completed surveys: trip information and socioeconomic data

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)

		Car	PT	SM
ASC_{car}	0.958	1	0	0
ASC_{PT}	1.57	0	1	0
β_{Time}	-0.016	TimeCar_n	TimePT_n	0
β_{CostLow}	-0.143	$\text{CostCar}_n \cdot \text{LowIncome}_n$	$\text{CostPT}_n \cdot \text{LowIncome}_n$	0
β_{CostMed}	-0.198	$\text{CostCar}_n \cdot \text{MedIncome}_n$	$\text{CostPT}_n \cdot \text{MedIncome}_n$	0
β_{CostHigh}	-0.105	$\text{CostCar}_n \cdot \text{HighIncome}_n$	$\text{CostPT}_n \cdot \text{HighIncome}_n$	0
β_{Distance}	-0.125	0	0	Distance_n

Synthetic sample (1)



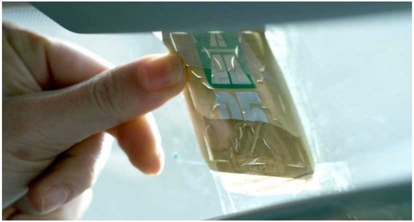
Distance between O and D divided in three parts: $d_{1n} + d + d_{2n}$

- 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
- TimeCar_n:
  - d_1 and d_2: 15 km/h
  - d: [45, 70] km/h
- 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)
- $\text{Distance}_n = d_{1n} + d + d_{2n}$
- Income level: Federal Statistical Office (2016)

Benchmark (1)



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

- $B^0 = 0$ CHF
- $F^{car} = 54.53$ CHF
- $c^{car} = 0.44$ CHF
- $F^{PT} = 22.96$ CHF

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

Benchmark (2)

Situation	Fare	Toll	D_{PT} (%)	D_{car} (%)	D_{SM} (%)	EMU
Initial	3.27	0	57.50	36.22	6.28	156.27
Optimized	1.56	2.30	71.80	23.02	5.18	163.77

- 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

- 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

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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