THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

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THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

TEAM

Departamento de Ingeniería de Transporte y Logística (DITL)

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Assistant Professor

Juan Carlos Muñoz
Professor
OUTLINE

- Limited-stop services
- Designing Limited-stop services
- Naïve approach to passenger assignment
- Case study – magnitude of the error
- Conclusion
LIMITED-STOP BUS SERVICES

Travel times :)  
Waiting times :(  
Transfers :(  
Operator costs :)
THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

LIMITED-STOP BUS SERVICES

- TransMilenio Bogotá

- 45,000 pax/h
- 25 km/h
THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

DESIGNING LIMITED-STOP BUS SERVICES

- Service generation problem
- Service design problem
- Passenger assignment problem

\[ X_{i}^{w,l} \quad Y_{j}^{w,1} \]

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THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

DESIGNING LIMITED-STOP BUS SERVICES

- Service generation problem

- Service design & Passenger assignment problem

Frequency Optimization Problem

Passenger Assignment Problem

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DESIGNING LIMITED-STOP BUS SERVICES

- Service design & Passenger assignment problem

  Frequency Optimization Problem \[\rightarrow\] Passenger Assignment Problem

Minimize *Total Social Cost*

  Operating cost \[\rightarrow\] User cost

Individual passengers minimizes their own travel time

This argument is invalid when capacity constraints are active
EXAMPLE

- Meal Distribution in Airplane

- # Passengers – 100
- Meal preferences
  - Meat – 50
  - Veg. – 30
  - Meat / Veg. – 20
EXAMPLE

- Meal Distribution in Airplane

1. Cost is very low / No capacity

   Social Optimum
   - Meat – 70
   - Veg. – 50

2. Cost is considered / With capacity

   Social Optimum
   - Meat – 50
   - Veg. – 50

   User Optimum
   - Meat – 60
   - Veg. – 40

   # Passengers – 100

   Meal preferences
   - Meat – 50
   - Veg. – 30
   - Meat / Veg. – 20

   10 Passengers will not be pleased
THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

EXAMPLE

- Meal Distribution in Airplane

1. Cost is very low / **No capacity**
   - **Social Optimum**
     - Meat – 70
     - Veg. – 50
   - **User optimum**
     - ✓ Selfish
     - ✓ Good forecast

2. Cost is considered / **With capacity**
   - **Social Optimum**
     - Meat – 50
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   - **User optimum**
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THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

DESIGNING LIMITED-STOP BUS SERVICES

- Service design & Passenger assignment problem

  Minimize Total Social Cost

  Operating cost

  User cost

- Key challenges
  - Non-linear problem
  - Passenger assignment is not trivial
THE IMPACT OF ASSUMING ALTRUISTIC BEHAVIOR IN THE LIMITED-STOP BUS SERVICE DESIGN PROBLEM

BEHAVIOR

- Itineraries

O – D pair (1 → 4)

L1

L2

L3

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ASSUMPTIONS

- Passengers follow Itineraries
- Make forward transfers
- Predefined set of services
- Over a given corridor
Objective: Minimize total social cost

\[
\text{Minimize} \left\{ \sum_{l \in \mathcal{L}} C_l \cdot f_l, \quad x_{ij}^{w,l} \right\}
\]

\[
+ \theta_{wt} \left\{ \sum_{w \in \mathcal{W}} \sum_{l \in \mathcal{L}} \sum_{(i,j) \in \mathcal{S}_l} \left( \frac{k}{f_l} \right) \cdot x_{ij}^{w,l} \right\}
\]

\[
+ \theta_{tt} \left\{ \sum_{w \in \mathcal{W}} \sum_{l \in \mathcal{L}} \sum_{(i,j) \in \mathcal{S}_l} t_{ij}^l \cdot x_{ij}^{w,l} \right\}
\]

s.t.: non-negativity and flow conservation.
EXAMPLE

- Meal Distribution in Airplane

1. Cost is very low / No capacity

Social Optimum

Meat – 70
Veg. – 50

User optimum

✓ Selfish
✓ Good forecast
What if we want to model Capacity?
**BEHAVIOR V/S CAPACITY**

- **Objective:** Minimize total social cost

\[
\begin{align*}
\text{Minimize } & \sum_{l \in \mathcal{L}} C_l \cdot f_l \\
& + \theta_{wt} \left( \sum_{w \in \mathcal{W}} \sum_{l \in \mathcal{L}} \sum_{(i, j) \in \mathcal{S}_l} \left( \frac{k}{f_l} \right) \cdot x_{ij}^{w, l} \right) \\
& + \theta_{tt} \left( \sum_{w \in \mathcal{W}} \sum_{l \in \mathcal{L}} \sum_{(i, j) \in \mathcal{S}_l} t_{ij}^l \cdot x_{ij}^{w, l} \right)
\end{align*}
\]

- **Capacity constraints**

\[
\sum_{(i, j) \in \mathcal{S}_l} \sum_{w \in \mathcal{W}} x_{ij}^{w, l} \cdot \beta_{a}^{ij} \leq f_l \cdot b_l, \quad l \in \mathcal{L}, a \in \mathcal{A}
\]

s.t.: non-negativity and flow conservation.
EXAMPLE

- Meal Distribution in Airplane

2. Cost is considered / **With capacity**

- **Social Optimum**
  - Meat – 50
  - Veg. – 50
  - **X**

- **User optimum**
  - ✓ Selfish
  - ✓ Good forecast
GAPS

- Our previous works have addressed this
  - Leiva et al. (2010)
  - Larrain et al. (2013)
  - Soto et al. (2017)

- Error induced by this simplification has not been studied

- Researchers are using this
Dimensioning the Effect of Direct Approach

- Solve the Naïve Approach
  - Service Design \( (f_l^*) \)
  - Passenger Assignment \( (x_s^{w,l}) \)
    - Altruistic
    - May not be consistent with reality

- Realistic Passenger Assignment

  How bad is this solution?

- Unconstrained passenger assignment \( (x_s^{w,l}) \)
  - Given Service Design \( (f_l^*) \)
  - Passenger Assignment \( (x_s^{w,l}) \)

**Compare**

Altruistic PA \( (x_s^{w,l}) \) V/S Unconstrained PA \( (x_s^{w,l}) \)
Performance Indicators

1) Level of passenger-kilometer (PKM) diversion

\[ \%\Delta pkmD = 100 \left( \frac{\sum_{l \in L} \sum_{w \in W} \sum_{s \in S} \left( \max_{l \in L, w \in W, s \in S} \left\{ x_{s}^{w,l} - x_{s}^{w,l}, 0 \right\} \cdot d_{s}^{l} \right)}{\sum_{l \in L} \sum_{w \in W} \sum_{s \in S} \left( x_{s}^{w,l} \cdot d_{s}^{l} \right)} \right) \]

2) Level of infeasibility in the service design

\[ \%\Delta f_{l} = 100 \left( \max_{a \in A} \left\{ \frac{\max_{w \in W} \sum_{s \in S} x_{s}^{w,l} \cdot \beta_{a}^{s}}{b_{l}} - \frac{f_{l}^{*}}{f_{l}^{*}}, 0 \right\} \right), \quad \forall l \in L \]
Case Study

- A five stop bus corridor with three services.
- Passengers follow itineraries to reach their destination.
- Only allow forward transfers.
- Neglect congestion.

![Graph]

**Travel demand matrix (pax/h)**

<table>
<thead>
<tr>
<th>O-D</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>10,000</td>
<td>8,000</td>
<td>1,000</td>
<td>5,000</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
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Experiments

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87

- **Base scenario**
  - Bus capacity \( (b) \) = 50 (pax/bus)
  - Value of waiting time \( (\theta_{wt}) \) = 100 (CLP/min)
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Impact with Bus Capacity

Passenger-Kilometer (PKM) Diversion

PKM Diversion

Bus capacity (pax/bus)

Capacity constraints are not active

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Impact with Bus Capacity

Infeasibility in Service Design

Level of Infeasibility in Service Design

Bus capacity (pax/bus)
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Impact with Value of Waiting Time

Passenger-Kilometer (PKM) Diversion

PA is governed by user cost

Different set of attractive lines
Different set of affected OD pairs

PKM Diversion

Value of waiting time

W3 & W9
W4 & W9
W4 & W9
W4

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Impact with Value of Waiting Time

Infeasibility in Service Design

Level of Infeasibility in Service Design

- L1
- L2
- L3

Value of waiting time

Additional Frequency

0% 10% 20% 30% 40% 50% 60% 70% 80% 90%

0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150 1200
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CONCLUSIONS

- Altruistic passenger assignment is inconsistent with the reality.
- Naïve approach underestimates the required frequencies.
- Its impact might be pronounced more in congested networks.
Thank you

Questions?
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The Impact of Assuming Altruistic Behavior in the Limited-Stop Bus Service Design Problem

Results for Base Scenario

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<td></td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>5.4 %</td>
<td>L1 9.1 %, L2 11.1 %, L3 0.0 %</td>
</tr>
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Load Profile for Altruistic Behavior

Load Profile for Unconstrained Behavior
CONCLUSIONS

- Altruistic passenger assignment is inconsistent with the reality.
- Naïve approach underestimates the required frequencies.
- Its impact might be pronounced more in congested networks.

- Similar experiments for - Routes instead of itineraries.
- Not providing enough capacity by just a little bit may affect much more people than if we fail by a large amount.