A short discussion about travel demand models

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Travel demand

- Most people don’t travel for the sake of it
- Travel demand = derived demand
- Results of many choices:
  - Choice of activity
  - Choice of destination
  - Choice of departure time
  - Choice of transportation mode
  - Choice of access point (parking, bus stop)
  - Choice of itinerary
  - Etc...
Route choice for car drivers
Route choice for car drivers

- **Assumption #1**: drivers prefer the fastest route
- **Warning**:  
  - Their presence affects the other drivers  
  - More cars = increased travel time
- **So...**  
  - Travel time influences route choice  
  - Route choice influences travel time
A simple example

\[ x : 10^3 \text{ veh/h} \]
\[ t : \text{time} \]

\[ t = 50 + x \]
\[ t = 10x \]

6000 veh/h
A simple example

$x : 10^3 \text{veh/h}$
$t : \text{time}$

Left-top: $t = 83$
Bottom-right: $t = 83$

Equilibrium

$t = 50 + x$
$x = 3$
$t = 53$

$t = 50 + x$
$x = 3$
$t = 53$

$t = 10 \times x$
$x = 3$
$t = 30$
A simple example

\[ x : 10^3 \text{ veh/h} \]
\[ t : \text{time} \]

\[ t = 50 + x \]
\[ t = 10 + x \]

6000 veh/h

6000 veh/h
A simple example

\[ x : 10^3 \text{ veh/h} \]
\[ t : \text{time} \]

Left-top: \( t = 83 \)
Bottom-right: \( t = 83 \)
New path: \( t = 70 \)

No more equilibrium
A simple example

\[ x : 10^3 \text{ veh/h} \]
\[ t : \text{time} \]

1000 veh change
Left-top \(\rightarrow\) new path

Left-top: \( t=82 \)
Bottom-right: \( t=93 \)
New path: \( t=81 \)

\[ t = 10x \]
\[ x = 3 \]
\[ t = 30 \]

\[ t = 50 + x \]
\[ x = 2 \]
\[ t = 52 \]

\[ t = 50 + x \]
\[ x = 3 \]
\[ t = 53 \]

\[ t = 10x \]
\[ x = 4 \]
\[ t = 40 \]
A simple example

\[ x : 10^3 \text{ veh/h} \]
\[ t : \text{time} \]

1000 veh change
Bottom-right → new path

Left-top: \[ t = 92 \]
Bottom-right: \[ t = 92 \]
New path: \[ t = 92 \]

Equilibrium

\[ t = 50 + x \]
\[ x = 2 \]
\[ t = 52 \]

\[ t = 10 x \]
\[ x = 4 \]
\[ t = 40 \]

6000 veh/h
A simple example

- A new infrastructure is built
- Before, travel time = 83 minutes
- After, travel time = 92 minutes

Increasing the physical capacity of the network does not necessarily increase the mobility

- Braess’ paradox
Polluters pay principle

- Concept of marginal travel time
  \[ t = 50 + x \quad \text{Marginal time} = 1 \]
  \[ t = 10 + x \quad \text{Marginal time} = 1 \]
  \[ t = 10 x \quad \text{Marginal time} = 10 \]
- Drivers are tolled proportionally to the nuisance they produce
- 1 min marginal travel time = 1€
- **Assumption #2**: drivers prefer the cheapest route
Back to the simple example

x : $10^3$ veh/h

6000 veh/h

mtt = 10
x = 3

mtt = 1
x = 0

mtt = 1
x = 3

mtt = 1
x = 3

mtt = 1
x = 3

6000 veh/h

Equilibrium

Left-top: 11€
Bottom-right: 11€
New path: 21€
Behavioral assumption?

- Do people minimize time?
- Do people minimize cost?
- Each assumption gives different results
- Behavior is more complex...
Time is money

- Path 1: 11€ - 83 minutes
- Path 2: 11€ - 83 minutes
- Path 3: 21€ - 70 minutes

- Would you be willing to pay 10€ to save 13 minutes?
- **Assumption #3**: drivers consider both time and cost
- But how do we identify the best path then?
Random utility models

- **Idea**: drivers combine cost and time into a number called “utility”
- The selected route is the one with the largest utility.
- Example with two routes:
  \[
  U_1 = -\beta t_1 - \gamma c_1 \\
  U_2 = -\beta t_2 - \gamma c_2 
  \]
- $\beta, \gamma > 0$
Random utility models

\[ U_1 = -\beta t_1 - \gamma c_1 \]
\[ U_2 = -\beta t_2 - \gamma c_2 \]

- \( U_1 > U_2 \) if \( -\beta t_1 - \gamma c_1 \geq -\beta t_2 - \gamma c_2 \)

\[ \frac{-\beta}{\gamma} t_1 - c_1 \geq -\frac{\beta}{\gamma} t_2 - c_2 \]

\[ c_1 - c_2 \leq -\frac{\beta}{\gamma} (t_1 - t_2) \]
Random utility models

- Dominated cases:
  - $c_1 > c_2$ and $t_1 > t_2$: 2 is dominating 1
  - $c_2 > c_1$ and $t_2 > t_1$: 1 is dominating 2
- What about the trade-offs for non-dominated cases?
Random utility models
Random utility models
Random utility models

- Need for a random term
- Now, probability must be used

\[
\begin{align*}
U_1 & = -\beta t_1 - \gamma c_1 + \varepsilon_1 \\
U_2 & = -\beta t_2 - \gamma c_2 + \varepsilon_2
\end{align*}
\]

- \( P(1) = P(U_1 > U_2) \)
- Most famous model : the multinomial logit model
Multinomial logit model

\[ U_{in} = V_{in} + \varepsilon_{in} = \beta_1 x_{in1} + \beta_2 x_{in2} + \ldots + \varepsilon_{in} \]

where \( x \) include time, cost, number of speed bumps, number of left turns, type of routes, etc.

\[ P_n(i|C_n) = \Pr(U_{in} \geq U_{jn} \ \forall j \in C_n) \]

\[ P_n(i|C_n) = \frac{e^{V_{in}}}{\sum_{j \in C_n} e^{V_{jn}}} \]
Value of time in Switzerland

- We can measure the willingness to pay for travel time savings


<table>
<thead>
<tr>
<th>WTP at sample mean</th>
<th>Business</th>
<th>Commuting</th>
<th>Leisure</th>
<th>Shopping</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT travel time (CHF/hour)</td>
<td>49.57</td>
<td>27.81</td>
<td>21.84</td>
<td>17.73</td>
</tr>
<tr>
<td>Car travel time (CHF/hour)</td>
<td>50.23</td>
<td>30.64</td>
<td>29.2</td>
<td>24.32</td>
</tr>
<tr>
<td>Headway red. (CHF/hour)</td>
<td>14.88</td>
<td>11.18</td>
<td>13.38</td>
<td>8.48</td>
</tr>
<tr>
<td>Interchange red. (CHF/change)</td>
<td>7.85</td>
<td>4.89</td>
<td>7.32</td>
<td>3.52</td>
</tr>
</tbody>
</table>
## Value of time in Switzerland

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<tr>
<td>PT Travel time (€/h)</td>
<td>30.2</td>
<td>17.0</td>
<td>13.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Car travel time (€/h)</td>
<td>30.6</td>
<td>18.7</td>
<td>17.8</td>
<td>14.8</td>
</tr>
<tr>
<td>Headway red. (€/h)</td>
<td>9.1</td>
<td>6.8</td>
<td>8.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Interchange red. (€/change)</td>
<td>4.8</td>
<td>3.0</td>
<td>4.5</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Optimal pricing

- Price = $z$, Population = $N$
- Choice model:
  \[ P(\text{choosing the train} \mid z) \]
- Number of people choosing the train:
  \[ N \cdot P(\text{choosing the train} \mid z) \]
- Revenues:
  \[ R(z) = N \cdot P(\text{choosing the train} \mid z) \cdot z \]
- Optimal pricing:
  \[ \max_z R(z) \]
Recent developments in route choice

Route choice modeling difficult because
- Large number of alternatives
- High structural correlation due to the physical overlap of paths
- Difficulty to collect data (reports, GPS)

Solutions we have proposed
- Sampling of alternatives
- Concept of subnetworks
- Measurement equations
Summary

- Travel demand is complex
- Simple assumptions are useful but not sufficient
- Need to analyze the situation as a whole (beeware of the Braess paradox)
- Observing and measuring behavior is critical (ex: willingness to pay)
- Random utility models are at the core of disaggregate demand modeling

Hot topic: route choice models