A Route Choice Model Based on Mental Representations

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Agenda

1. Introduction
2. Methodology
3. Case study
4. Application
5. Conclusion

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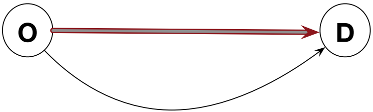
Route choice (RC)

Predict the route that a traveler would choose to go from the origin (O) to the destination (D) of her trip.



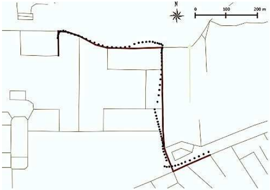
- One of the key travel demand models.
- Core of traffic assignment for planning and real-time operations.
- Need to go beyond the shortest/ fastest path models.

Random utility models (RUMs) for route choice

1. Decision maker n
2. Alternatives
   - **Choice set** $\mathcal{C}_n$
   - Route representation: path p
   - Paths as link sequences $p \in \mathcal{C}_n$
3. Attributes of alternatives x_{pn}

   Usually link additive (travel time, length, etc.), but also path based.
4. Characteristics of decision maker z_n

   Usually missing.
5. Decision rule $\mathcal{P}(p|\mathcal{C}_n)$
   - Utility maximization
   - $\mathcal{P}(p|\mathcal{C}_n) = Pr(U_{pn} \geq U_{qn} \forall q \in \mathcal{C}_n)$



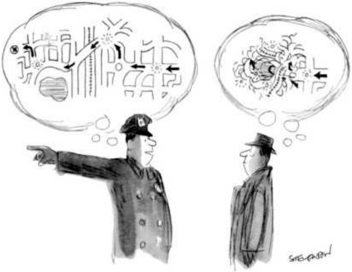
Motivation

Estimation of RUMs with RP[1] data and path assumption is challenging

Operational limitations

- Data
- Choice set
- Structural correlation

Behavioral limitations



[1] Revealed preference.

State-of-the-art

- Path based models
  1. Complex;
  2. Fail to capture observed behavior.
- No realistic, yet simple model, based on RP data has been proposed.
- Few attempts to use abstract elements related to perceptions
  1. [Ben-Akiva et al., 1984] path generation and sampling;
  2. [Frejinger and Bierlaire, 2007] capturing correlation.

Proposed framework

1. Simple model exploiting RP data
2. Not based on paths
3. Key feature: *mental representations*
4. The general framework may be network-free, yet applicable to traffic assignment.

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Backbone of the framework

A *path* is solely the manifestation of the route choice –the way the traveler implements her decision to take a specific route.

How can we represent a route in a behaviorally realistic way without increasing the model complexity?

- Choice takes place at a higher conceptual level.

  $\rightarrow$ Mental Representation Item (*MRI*) = *main modeling element*

Outline of the methodology

1. Definition of the *MRI*:
    1. Empirical evidence through simple qualitative analyzes
    2. Literature review in relevant fields
2. Definition of a RUM model based on *MRI*:
    1. Choice set $\mathcal{C}_n$
    2. Explanatory variables x_{in}, z_n
    3. Specification of the deterministic utility function V_{in}
    4. Assumption about the error terms ε_{in}

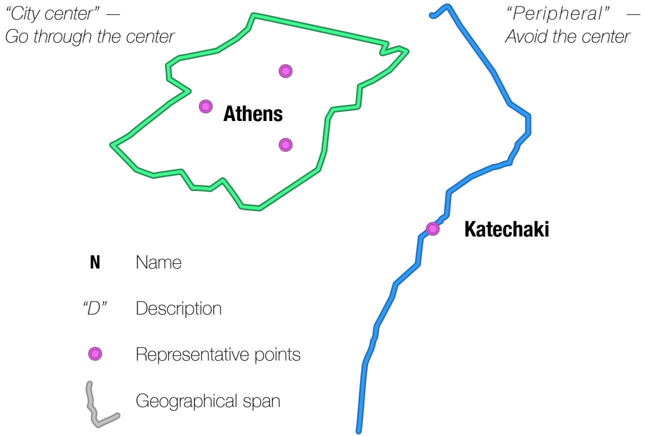
Mental Representation Item (*MRI*)

- *MRIs* are associated with mental representations used in daily language to describe a route.
- An *MRI* is an item characterising the mental representation of an itinerary:

  E.g. a highway, the city center or a bridge.

The *MRI* components

Perceptual: a name and a description; Tangible: a point and an area



The *MRI* definition

The exact definition of the *MRI* is context dependent, and must be designed such that:

1. It has a meaningful behavioral interpretation, and
2. Its level of aggregation is high enough for the model to be simple and operational, and low enough for the model to be usefull.

Definition of the alternatives

A route is either one-*MRI* or a sequence-of-*MRIs*.

The number of *MRIs* should be kept low so that the number of sequences-of-*MRIs* is also low and can be enumerated.

Issues:

1. How to relate available data to *MRI* alternatives; and
2. How to specify the utility function for the abstract alternatives.

$\rightarrow$ Different heuristics can be considered and evaluated.

From data to *MRIs*

- Interviews and surveys.
- GPS devices and smartphones.

Maximum likelihood estimation:

Obtain the contribution of each piece of data to the likelihood function. Let i be an alternative of the *MRI* model, and y an observation, then:

$$\sum_i P(y|i) \cdot P(i|C, x_{in}, z_n)$$

where $P(y|i)$ is the measurement model, $P(i|C, x_{in}, z_n)$ is the choice model. Associating each piece of data to a single alternative, so that $P(y|i)$ takes values 0 and 1 only, is convenient. For more complex measurement models, we refer to [Bierlaire and Frejinger, 2008] and [Chen and Bierlaire, 2013].

Specification of the utility function

Probably the most complex part. We need to go from abstract back to specific.

The main modeling element is a mental representation. This has implications for the specification of the utility functions:

! The attributes are fuzzy and based on perceptions rather than objective measurements.

✓ Possibilities to investigate the impact of perception on behavior:

1. Model perceptions –e.g. using latent variables;
2. Network-free approach –e.g. using the level of service of the *MRIs*;
3. Use network data to generate attributes for each *MRI* and specify the utility functions –what we do in the case study.

Operational approach using network data

We propose two heuristics assuming that a network model is available:

✓ Deterministic approach.

→ Unique representative path for each *MRI*.

x Expected maximum utility (EMU).

→ Path enumeration and logsum.

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Borlänge data

✓ GPS data → `map-matched trajectories`

✓ Borlänge road network:

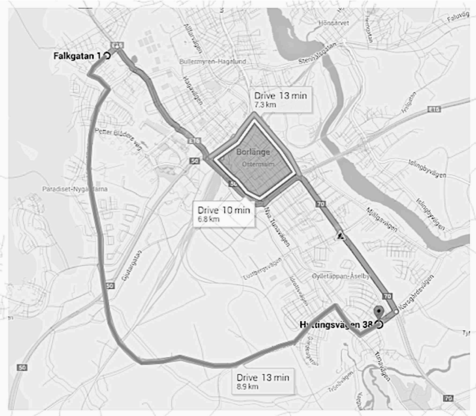
1. 3077 nodes and 7459 unidirectional links
2. Link travel times
3. Clear choices

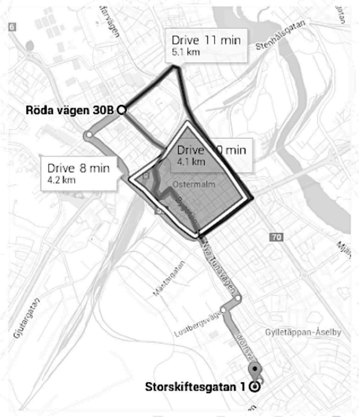
- We use a sample of 139 observations.
- We focus on the simplest possible case where each route is described my one-*MRI* and a common choice set $\mathcal{C}$ for all travelers.

Borlänge road network

Borlänge *MRI* CS

$\mathcal{C} = \{$ *1: through the city center (CC),*
2: clockwise movement around the CC,
3: counter-clockwise movement around the CC,
4: avoid the CC $\}$

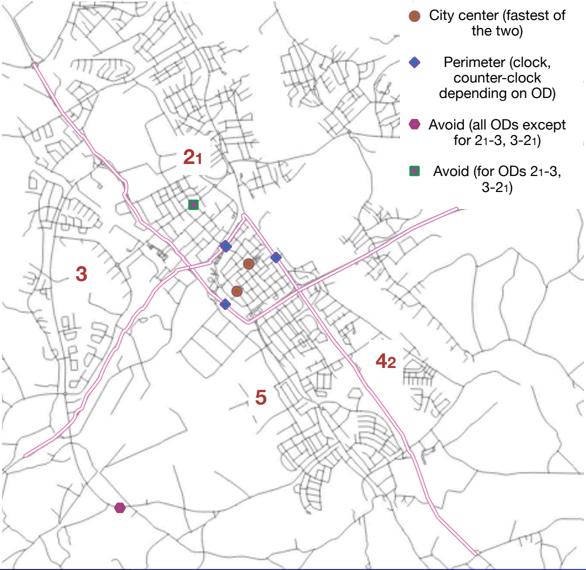




Definition of the *MRIs* in Borlänge

Name	Description	Geographical span	Representative node
City center (CC) of Borlänge	Go through the CC	Every link inside the perimeter	See Fig. on slide 21
Street name	Around the center	Every link on the perimeter	See Fig. on slide 21
Street name	Around the center	Every link on the perimeter	See Fig. on slide 21
Street name	Avoid the center (Peripheral)	Every other link	See Fig. on slide 21

Representative nodes



Example of observed routes (1)

Around the CC movements

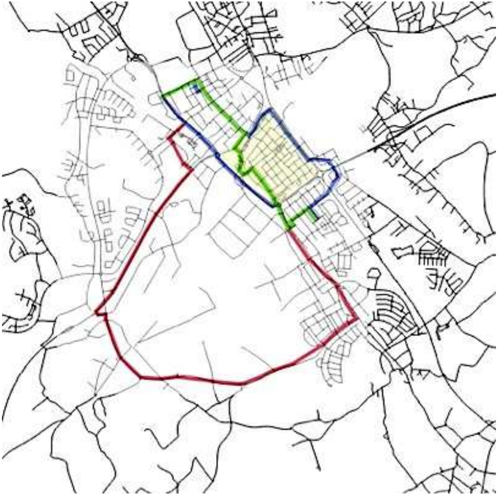
Example of observed routes (2)

Avoid the CC alternatives

Example of observed routes (3)

Through the CC movements

Example of *MRI* choice set



——— chosen alternative (through CC)

——— around CC alternatives (clock and counter-clockwise)

——— avoid CC alternative

Specification of utility functions and attributes of the alternatives

Deterministic approach

1. For each *MRI* determine a representative node m (OD dependent).
2. Calculate the fastest path from O to m.
3. Calculate the fastest path from m to D.
4. Use the attributes of the generated path for the *MRI*.

Choice model

For high levels of aggregation, logit can be assumed:

$$\mathcal{P}_n(i|\mathcal{C}) = \frac{e^{\mathcal{V}_{ni}}}{\sum_{j \in C} e^{\mathcal{V}_{jn}}}$$

Specification table of model 1

Piecewise linear travel time for the around alternatives

Parameter name	Through CC	Around clock CC	Around counter CC	Avoid CC
ASC_{CC}	0	0	0	0
ASC_{AROUND}	0	1	1	0
ASC_{AVOID}	0	0	0	1
$\beta TIME_{CC}$	TT (min)	0	0	0
$\beta TIME_{AROUND}^{(0-10min)}$	0	TT (min)	TT (min)	0
$\beta TIME_{AROUND}^{(>10min)}$	0	TT (min)	TT (min)	0
$\beta TIME_{AVOID}$	0	0	0	TT (min)
$\beta LEFT$	# left turns	# left turns	# left turns	# left turns
βIS	# intersections	# intersections	# intersections	# intersections

Specification table of model 2

Length

Parameter name	Through CC	Around clock CC	Around counter CC	Avoid CC
ASC_{CC}	0	0	0	0
ASC_{AROUND}	0	1	1	0
ASC_{AVOID}	0	0	0	1
$\beta LENGTH_{CC}$	Length (km)	0	0	0
$\beta LENGTH$	0	Length (km)	Length (km)	Length (km)
$\beta LEFT$	# left turns	# left turns	# left turns	# left turns
βIS	# intersections	# intersections	# intersections	# intersections

Estimation results

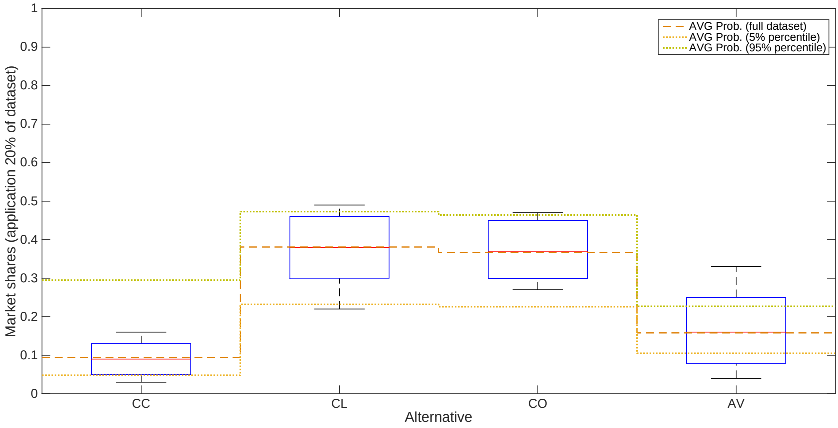
Parameters	**Model 1** Parameter value; Rob. Std (Rob. t-test 0)	**Model 2** Parameter value; Rob. Std (Rob. t-test 0)
ASC_{AROUND}	-2.11; 1.44; (-1.47)	-0.975; 1.67; (-0.58)
ASC_{AVOID}	1.87; 2.09; (0.89)	0.307; 1.70; (0.18)
$\beta TIME_{CC}$	-0.772; 0.274; (-2.82)	
$\beta TIME_{AROUND}^{(0-10min)}$	-0.286; 0.165; (-1.74)	
$\beta TIME_{AROUND}^{(>10min)}$	-0.616; 0.216; (-2.86)	
$\beta TIME_{AVOID}$	-0.583; 0.187; (-3.11)	
$\beta LENGTH$		-0.871; 0.173; (-5.03)
$\beta LENGTH_{CC}$		-1.48; 0.493; (-2.99)
$\beta LEFT$	-0.288; 0.130; (2.22)	-0.270; 0.143; (-1.89)
βIS	-0.0474; 0.022; (-2.16)	-0.0631; 0.018; (-3.42)
Number of observations	139	139
Number of parameters	8	6
$\overline{\rho}$	0.375	0.416
$\mathcal{L}(0)$	-183.201	-183.201
$\mathcal{L}(\hat{\beta})$	-106.563	-101.064

Forecasting results (Model 1)

1. Randomly select 80% of the data for estimation.
2. Apply the model in the rest 20%.
3. Repeat 100 times.

→ Check market shares (MS), predicted probabilities, elasticities.

Boxplot of MS from the application in 20% of the data and CI from the estimation with the full dataset



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Application

Traffic assignment

1. Metropolis-Hastings (MH) algorithm [Flötteröd and Bierlaire, 2013] to sample paths given the OD and $\mathcal{C}$.

2. The probability of each *path* p to be selected, given the OD and $\mathcal{C}$, is:

   $P(p|\mathcal{C}) = \sum_i P(p|i) \cdot P(i|\mathcal{C})$

   where $P(p|i)$ is the probability of path p to selected given *MRI* alternative i, and $P(i|\mathcal{C})$ is the choice model.
   For the assignment we need an indicator function $\delta(p, i)$, which is 1 if the sampled path is consistent with *MRI* i, and 0 otherwise.

Application

Route guidance

Provision of information in an aggregate manner:

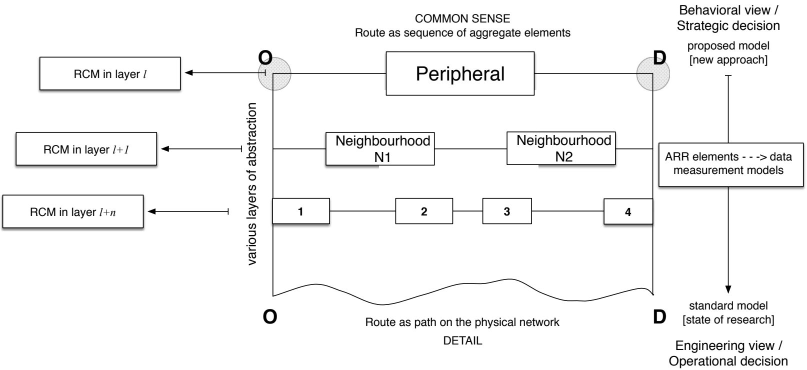
1. Guidance on VMS[2]
2. Radio announcements
3. Oral instructions in in-vehicle navigation systems

[2] Variable message signs.

Hierarchical ordering of the decision process

Multi-level hierarchical structure ∼Normative Pedestrian Flow Theory

[Hoogendoorn, 2001]



Model structure

Layer ℓ

- Choice set: list of *MRIs* $\mathcal{C}_\ell$.
- Choice model:

$$P_\ell(i|\mathcal{C}_\ell;\beta^\ell)$$

Layer $\ell+1$

- Choice set: list of *MRIs* $\mathcal{C}_{\ell+1}$.
- Choice model:

$$P_{\ell+1}(i|\mathcal{C}_{\ell+1};\beta^{\ell+1})$$

Behavioral consistency

- All layers refer to the same choice.
- Level of granularity varies.
- Analysis can be performed in any layer.

Structural consistency

$$\bar{P}_\ell(i|\mathcal{C}_\ell;\beta^\ell) = \sum_{j\in\mathcal{C}_{\ell+1}} P(i|j,\mathcal{C}_\ell;\beta^\ell)P(j|\mathcal{C}_{\ell+1};\beta^{\ell+1})$$

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Conclusion

It is possible to have a meaningful model even with one-*MRI*.

Achievements

- Simplification of the choice set and hence the model.
- No need for sampling.
- Behaviorally realistic.
- Flexibility to the analyst.

Challenges

- Involved modeling.
- Data processing.

Future steps

1. Traffic assignment.
2. Generation of attributes → `EMU`
3. Consistency within the hierarchical structure.
4. *MRI* sequences and additional complexity → `Quebec GPS dataset`
5. Comparison & combination with RL model [Fosgerau et al., 2013]

THANK YOU!

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Descriptive statistics of the main variables

	mean	median	min	max	std.dev
TT_CC (min)	10.18	8.38	3.88	38.03	6.41
TT_CL (min)	9.98	8.18	2.86	38.93	6.32
TT_CO (min)	10.21	8.37	3.81	36.47	6.23
TT_AV (min)	11.80	13.12	2.66	38.58	11.81
L_CC (km)	7.65	5.21	1.88	42.91	7.39
L_CL (km)	7.84	5.47	1.57	43.82	7.30
L_CO (km)	7.95	5.48	2.33	42.62	7.23
L_AV (km)	9.18	9.04	1.54	42.29	8.90

alternative	# times chosen
Through CC	13
Clockwise	53
Counter-clockwise	51
Avoid CC	22

Predicted probabilities and elasticity of travel time