Activity-based models: an optimization perspective

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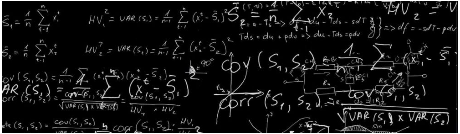
Outline

Introduction

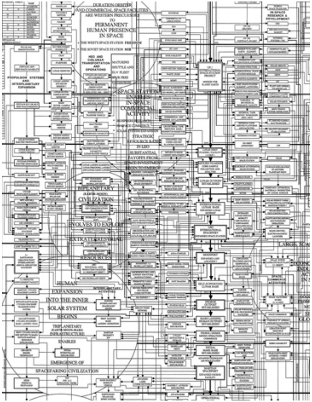
- Travel demand is derived from activity demand.
- Activity demand is influenced by socio-economic characteristics, social interactions, cultural norms, basic needs, etc. [Chapin, 1974]
- Activity demand is constrained in space and time [Hägerstraand, 1970].

Literature

Econometric models



Rule-based models



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State of the art: econometric approach

[Pinjari et al., 2011]

- *... individuals make their activity-travel decisions to maximize the utility derived from the choices they make.*
- *These model systems usually consist of a series of ... discrete choice models ... that are used to predict ... individuals' activity-travel decisions.*
- *these model systems employ econometric systems of equations ... to capture relationships between ... socio-demographics and ... attributes on the one hand and the observed activity-travel decision outcomes on the other.*

State of the art: econometric approach

[Pinjari et al., 2011]: main criticisms

- *individuals are not necessarily fully rational utility maximizers*
- *the approach does not explicitly model the underlying decision processes and behavioral mechanisms that lead to observed activity-travel decisions.*

State of the art: econometric approach

[Bhat, 2005]

- Multiple Discrete Continuous Extreme Value
- Based on first principles.
- Decision-maker solves an optimization problem, with a time budget.
- Several alternatives may be chosen.
- Model derived from KKT conditions.

Research question

Relax the *series of discrete choice models* approach

- The interactions of all decisions is complex.
- Sequence of models is most of the time arbitrary.

Integrated approach

Develop a model involving many decisions:

- activity participation,
- activity location,
- activity duration,
- activity scheduling,
- travel mode,
- travel route.

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Research objectives

- Integrated approach based on first principles.
- Theoretical framework: utility maximization.
- Individuals solve a scheduling problem.
- Important aspects: trade-offs on activity duration.

Outline

First principles

- Each individual n has a time-budget (a day).
- Each activity a considered by n is associated with a utility U_{an}.
- Individuals schedule their activities as to **maximize** the total utility, subject to their time-budget constraint.

Further assumptions

Individuals are time sensitive

- Have a desired *start time*, *duration* and/or *end time* for each activity
- Deviations from their desired times in the scheduling process decrease the utility function

Time

- Time horizon: 24 hours.
- Discretization: T time intervals.
- Trade-off between model accuracy and computational time.

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Space

- Discrete and finite set S of locations, indexed by s.
- For each individual, each activity is associated with a list of potential locations.

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Travel

- For each pair OD, list of possible modes.
- For each mode, list of possible routes.
- For each (O, D, m, r), $\rho(O, D, m, r)$ is the travel time.
- Exogenously given.

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Activities

Definition: Activity

An activity is associated with a location and a trip.

Activities

Location, mode and route choices

- Lunch at location A, followed by trip by bus on route A.
- Lunch at location A, followed by trip by bus on route B.
- Lunch at location A, followed by trip by car on route A.
- Lunch at location B, followed by trip by car on route B.

Constraint

Only one of the "duplicates" can be chosen.

Activities

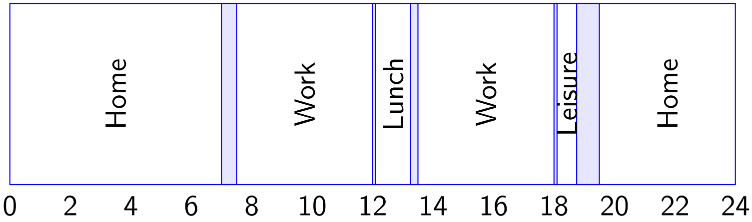
Given

- Set A of activities.
- Location s_a.
- Feasible time interval: $[\gamma_a^-, \gamma_a^+]$ (e.g. opening hours).

Decisions

- Participation: $w_a \in \{0, 1\}$.
- Starting time x_a, $0 \leq x_a \leq T$.
- Schedule: $z_{ab} \in \{0, 1\}$.
- Duration: $\tau_a \geq 0$.

Scheduling



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Categories

- [Castiglione et al., 2014]: mandatory, maintenance, discretionary.
- Flexible, somewhat flexible, not flexible.

Category

Activities that share the same preference profile.

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Preferences

Preferences

- desired starting time x_a^*,
- desired duration τ_a^*.

Penalties

- Starting early [Small, 1982]: $\theta_e \max(x_a^* - x_a, 0)$.
- Starting late [Small, 1982]: $\theta_\ell \max(x_a - x_a^*, 0)$.
- Shorter activity: $\theta_{ds} \max(\tau_a^* - \tau_a, 0)$.
- Longer activity: $\theta_{d\ell} \max(\tau_a - \tau_a^*, 0)$.

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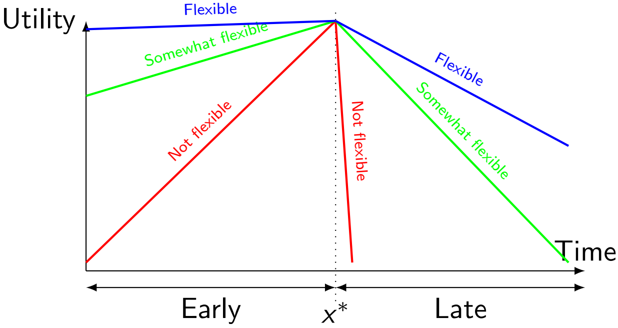
Preferences

Parameters depend on the category type



Disutility of travel

Each activity is followed by a trip

- Travel time from a to a^+: t_a.
- Depends on the next activity.

$$t_a = \sum_b z_{ab} \rho(s_a, s_b, m_a, r_a).$$

- Over variables can be included (cost, etc.)
- Note: If $s_a = s_b$, $\rho(s_a, s_a, m_a, r_a) = 0$
- Exception: last activity of the day (home).

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Utility function

An individual n derives the following utility from performing activity a, with a schedule flexibility k:

$$\begin{aligned} U_{an} = & \ \theta_e \max(x_a^* - x_a, 0) \\ & + \theta_\ell \max(x_a - x_a^*, 0) \\ & + \theta_{ds} \max(\tau_a^* - \tau_a, 0) \\ & + \theta_{d\ell} \max(\tau_a - \tau_a^*, 0) \\ & + c_{an} + \varepsilon_{an}, \end{aligned}$$

where ε_{an} are error components.

Utility function

Utility of a schedule

$$U_{sn} = \sum_a w_a U_{an} + \theta_t \sum_a \sum_b z_{ab} \rho(a, b, m_a, r_a)$$

Error components

$$\sum_a w_a \varepsilon_{an}$$

where ε_{an} normally distributed.

Utility function

Error terms

- Rely on simulation.
- Draw ε_{anr}, $r = 1, \ldots, R$.
- Optimization problem for each r.
- Utility: U_{anr}.

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Outline

Decision variables for individual n and draw r

For each (potential) activity a:

- Activity participation: $w_{anr} \in \{0, 1\}$.
- Starting time: $x_{anr} \in \{0, \ldots, T\}$.
- Duration: $\tau_{anr} \in \{0, \ldots, T\}$.
- Scheduling: $z_{abnr} \in \{0, 1\}$: 1 if activity b immediately follows a.

Objective function

Additive utility

$$\max \sum_{a \in A} w_{anr} U_{anr} + \theta_t \sum_{a \in A} \sum_{b \in A} z_{abnr} \rho(a, b, m_a, r_a).$$

Constraints

Time budget

$$\sum_{a \in A} w_{anr} \tau_{anr} + \sum_{a \in A} \sum_{b \in A} z_{abnr} \rho(a, b, m_a, r_a) = T, \; \forall n, r.$$

Time windows

$$0 \leq \gamma_a^- \leq x_{anr} \leq x_{anr} + \tau_{anr} \leq \gamma_a^+ \leq T, \; \forall a, n, r.$$

Constraints

Precedence constraints

$$z_{abnr} + z_{banr} \leq 1, \ \forall a, b, n, r.$$

Single successor/predecessor

$$\sum_{b \in A \setminus \{a\}} z_{abnr} = w_{anr}, \ \forall a, n, r,$$

$$\sum_{b \in A \setminus \{a\}} z_{banr} = w_{anr}, \ \forall a, n, r.$$

Constraints

Consistent timing

$$(z_{abnr} - 1)T \leq x_{anr} + \tau_{anr} + t_{anr} - x_b \leq (1 - z_{abnr})T, \ \forall a, b, n, r.$$

where

$$t_{anr} = \sum_{b \in A} z_{abnr} \rho(s_a, s_b).$$

Mutually exclusive duplicates

$$\sum_{a \in B_k} w_{anr} = 1, \ \forall k, n, r.$$

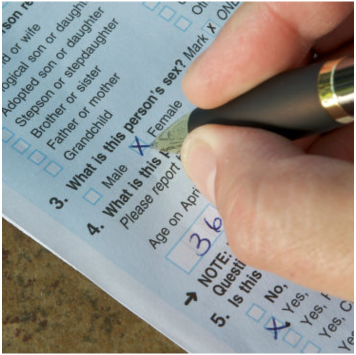
Optimization problem

Simulation-based optimization

- For each realization of the error terms, we have an optimal schedule.
- It includes all the choice dimensions (activity participation, location, duration, scheduling, and mode and route).
- We can generate an empirical distribution of chosen schedules.

Outline

Real data



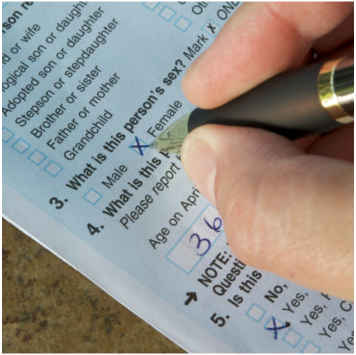
Dataset

- 2015 Swiss Mobility and Transport Microcensus.
- Daily trip diaries for 57'000 individuals.
- Records of activities and visited location.

Challenges: classical RP issues

- No information about unchosen alternatives.
- Latent preferences.

Real data

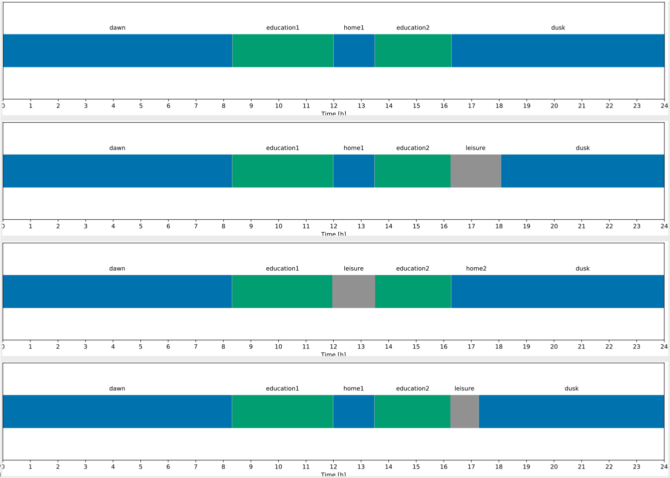


Assumptions

- Desired start times and durations are the recorded ones.
- Feasible time windows: average start and end times from out of sample distribution.
- Only the recorded locations are considered.
- Uniform flexibility profile across population.

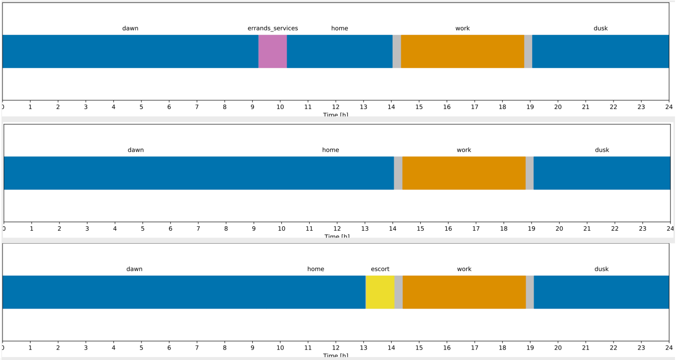
Individual 1 (weekday)

Optimal schedules generated for random draws of ε_{a_n}



Individual 2 (weekday)

Optimal schedules generated for random draws of ε_{a_n}



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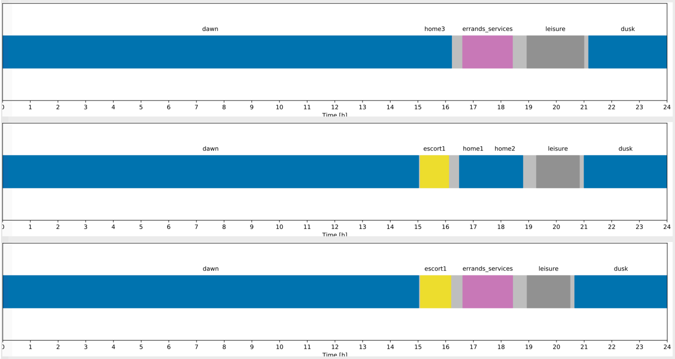
Individual 3 (weekday)

Optimal schedules generated for random draws of ε_{a_n}



Outline

Parameter estimation

Choice set generation

- Full set of schedules C_n is combinatorial, approximated with a sample of alternatives $\tilde{C}_n$
- Sampling protocol using Metropolis-Hastings algorithm [Flötteröd and Bierlaire, 2013]

Choice model estimation

- Include an EV error term to obtain a mixture of logit.
- Probability of choosing a schedule y for individual n is conditional on the parameters β_n, the variables x_n and the sampled choice set $\tilde{C}_n$ [Guevara and Ben-Akiva, 2013]
- Maximum likelihood estimators of the parameters:

$$\max_{\widehat{\beta}} L(y|\widehat{\beta}, X) = \prod_n P(y|x_n, \widehat{\beta}_n, \tilde{C}_n)$$

Conclusions

Achievements so far

- Formulation of the model.
- Applied on real data.
- The results make sense.
- We are able to draw from a distribution of activity schedules.

Ongoing work

- Parameter estimation.

Bibliography I

Bhat, C. R. (2005).
A multiple discrete-continuous extreme value model: formulation and application to discretionary time-use decisions.
Transportation Research Part B: Methodological, 39(8):679 – 707.

Castiglione, J., Bradley, M., and Gliebe, J. (2014).
Activity-Based Travel Demand Models: A Primer.
Transportation Research Board, Washington, D.C.

Chapin, F. S. (1974).
Human activity patterns in the city: Things people do in time and in space, volume 13.
Wiley-Interscience.

Bibliography II

Flötteröd, G. and Bierlaire, M. (2013).
Metropolis–hastings sampling of paths.
Transportation Research Part B: Methodological, 48:53–66.

Guevara, C. and Ben-Akiva, M. (2013).
Sampling of alternatives in logit mixture models.
Transportation Research Part B: Methodological, 58:185 – 198.

Hägerstraand, T. (1970).
What about people in regional science?
Papers in Regional Science.

Pinjari, A. R., Bhat, C. R., et al. (2011).
Activity-based travel demand analysis.
A Handbook of Transport Economics, 10:213–248.

Bibliography III

Small, K. A. (1982).
The scheduling of consumer activities: work trips.
American Economic Review.