Scheduling of daily activities: an optimization approach

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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].

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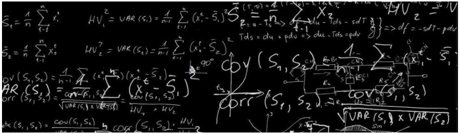
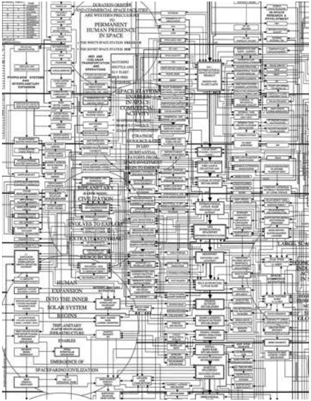
Literature

Econometric models



Rule-based models



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.*

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 all activity-based decisions:

- activity participation,
- activity pattern,
- location choice,
- time of day,
- duration.

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 i considered by n is associated with a utility U_{in}.
- Individuals schedule their activities as to **maximize** the total utility, subject to their time-budget constraint.

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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.

Space

- Discrete and finite set S of locations, indexed by s.
- Trips between location are modeled exogenously.
- For each (s_o, s_d), $\rho(s_o, s_d)$ is the travel time.
- Extensions to include mode and route choices are possible.

Activities

Definition: Activity

An activity requires a trip to/from a given location.

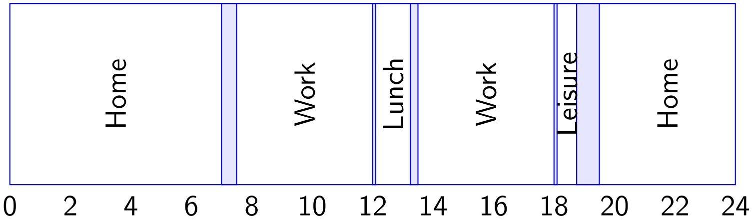
Activities

- Set A of activities.
- Location s_a.
- Starting time x_a, $0 \leq x_a \leq T$.
- Duration: $\tau_a \geq 0$.
- Feasible time interval: $[\gamma_a^-, \gamma_a^+]$ (e.g. opening hours).
- "Home": same, except for boundary conditions.

Modeling location choice

An activity that can take place at m locations is modeled as a set B_k of m activities with a unique location.

Scheduling



Categories

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

Category

Activities that share the same preference profile.

Preferences

Preferences

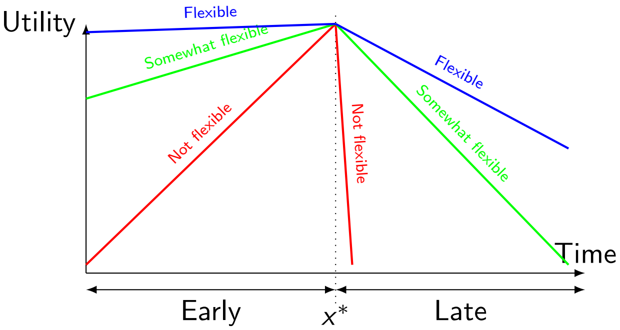
- desired starting time x_a^*,
- desired duration τ_a^*.

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: $\theta_{d\ell} \max(\tau_a - \tau_a^*, 0)$.

Preferences

Parameters depend on the category type



Disutility of travel

Traveling is part of the activity

- Travel from a to a^+ contributes to U_a: t_a.
- Exception: last activity of the day (home).
- In this version, travel choices are exogenous.

Utility function

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

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

where ε_{an} is a random term with mean 0 and variance 1.

Utility function

Error terms

- Rely on simulation.
- Draw ξ_{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.
- Travel time: t_{anr}: travel time from a to the next activity.

Objective function

Additive utility

$$\max \sum_{a \in A} w_{anr} U_{anr}$$

Constraints

Time budget

$$\sum_a \tau_{anr} = T, \ \forall n, r.$$

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

Travel time

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

Consistent timing

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

Mutually exclusive duplicates

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

Outline

Internal data set

Data collection

- One-week survey on planned daily schedules for 10 individuals.
- Planning across **week** and **day**.
- Resulting data (unavailable in traditional trip diaries):
  - Set of all considered activities and locations.
  - Preferences in terms of start times and duration.
  - Flexibilities for start times and duration.

Data set

- **Weekly plan:** filled on Sunday, considerations for next Mon-Sun
- Considered activities (*Which out-of-home activities do you plan to do this week?*):
  - Choice between 9 categories + 1 "other" option
  - Frequency of the activity
- Set of transportation modes (for travel time computations)
- Routine preferences:
  - Minimal daily duration at home (Mon-Fri and Sat-Sun)
  - Typical daily duration at work
  - Earliest departure from home (Mon-Fri and Sat-Sun)
  - Latest arrival at home (Mon-Fri and Sat-Sun)

Data set

- **Daily plan:** filled each day (Sun-Sat), considerations for the next day
- Considered activities (*Which activities do you plan to do tomorrow?*)
- Preferred times:
  - Start time: absolute value or relative, e.g. *"after work"*
  - End time
  - Duration
- Considered location(s) and feasible time windows for each
- Flexibility (early, late, short, long):
  - -1: not flexible
  - 0: moderately flexible (threshold value to be specified in minutes)
  - 1: flexible
- Other constraints (e.g. drop-off at home after grocery shopping)

Data set

- **Model input:**
  - All possible activities for the week (Mon-Fri and Sat-Sun)
  - All considered locations and travel times matrix (for the preferred mode(s), computed using Google Maps)
  - Individual flexibilities and preferred times for each activity
- **Output:**
  - Optimal schedule for 1 day (Mon-Fri or Sat-Sun)

Individual 1 (weekday)

- Considered activities $\rightarrow$ location(s):

$$\begin{aligned} \text{work} &\longrightarrow 1 \text{ (home)}, 2 \\ \text{education} &\longrightarrow 1 \\ \text{errands} &\longrightarrow 2, 3 \\ \text{fitness} &\longrightarrow 4 \\ \text{leisure/social} &\longrightarrow 5 \\ \text{lunch} &\longrightarrow 2 \end{aligned}$$

- Timing preferences and flexibility from daily schedules
- Preference for home time from week schedule

Individual 1 (weekday)

Optimal schedules generated for random draws of $\varepsilon_{a_n} \sim \mathcal{N}(0, 1)$

Individual 2 (weekday)

- Considered activities → location(s):

$$
\begin{aligned}
\text{work} &\longrightarrow 1 \text{ (home)}, 2 \\
\text{errands} &\longrightarrow 3, 4, 5 \\
\text{fitness} &\longrightarrow 1 \\
\text{leisure/social} &\longrightarrow 2, 6 \\
\text{lunch} &\longrightarrow 2
\end{aligned}
$$

Individual 2 (weekday)

Optimal schedules generated for random draws of $\varepsilon_{a_n} \sim \mathcal{N}(0,1)$

Conclusions

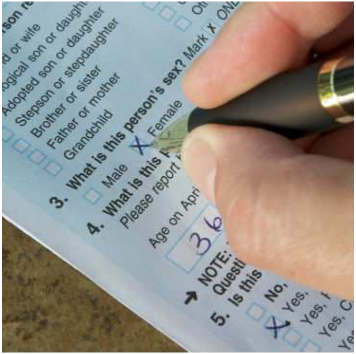
Achievements so far

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

Challenges

- Use of real data.
- Parameter estimation.

Conclusions



Real data

- 2015 Swiss Mobility and Transport Microcensus.
- Daily trip diaries for 20'000 individuals.
- Records of activities and visited location.
- Also: 2012–2015 London Travel Demand Survey.

Challenges: classical RP issues

- No information about unchosen alternatives.
- Latent preferences.

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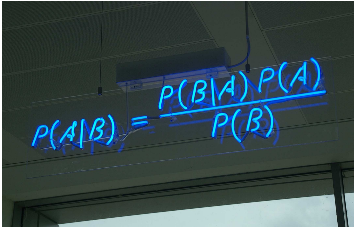
Conclusions



Parameter estimation

- Prior: $f(\beta)$.
- Data: $Y = (i_n, x_n)_{n=1}^{N}$.
- Likelihood: $L(Y|\beta)$.
- Parameters:

$$f(\beta|Y) \propto L(Y|\beta)f(\beta).$$

Challenges

- Metropolis-Hastings algorithm.
- Calculation of the likelihood.

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