Disaggregate activity scheduling models

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Outline

Introduction

Complexity of modern transportation systems requires complex travel demand models.

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].

Activity-based models

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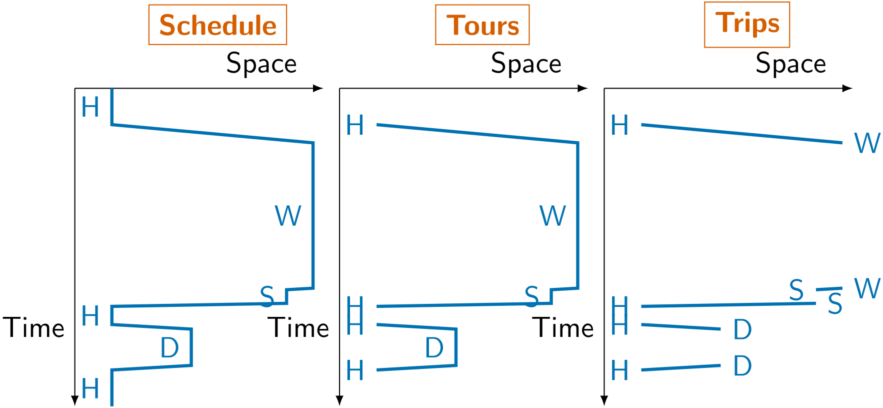
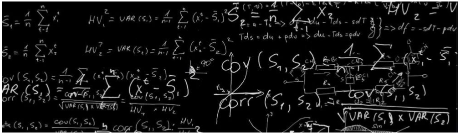
Travel demand models



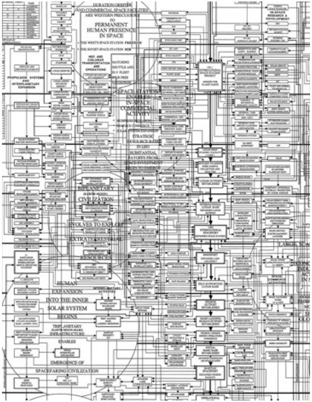
H: Home, W: Work, S: Shop, D: Dining out [Source: M. Ben-Akiva]

Literature

Econometric models



Rule-based models



Research question: can we combine the two?

	Econometric	Rule-based
Micro-economic theory	X	—
Parameter inference	X	—
Testing/validation	X	—
Joint decisions	—	X
Complex rules	—	X
Complex constraints	—	X

Integrated approach

Assumptions

- Individuals **are** utility maximizers.
- All decisions are made together.
- Decisions are subject to complex constraints and interactions.
    - Time constraint: to increase the activity duration, another activity is impacted.
    - Interaction constraints: if I leave home by bus, driving my car is not an option until I come back home.
    - Resource constraints: if my wife uses the only car in the household, driving the car is not an option for me.

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Integrated approach

Integrate the econometric and the rule-based approaches

- Utility associated with activity participation, duration, etc.
- Disutility associated with traveling.
- Complex interactions and constraints are captured by rules.

Mathematical programming

- Individuals are solving an optimization problem.
- Decisions: activity participation and scheduling.
- Objective function: utilities.
- Constraints: complex rules.

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.

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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

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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.
- For each (s_o, s_d), $\rho^m(s_o, s_d)$ is the travel time with mode m.
- Extensions to include route choices are possible.

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Activities

Definition: Activity

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

Activities

- Set A of activities.
- Location s_a.
- Transportation mode: m_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).

Activities

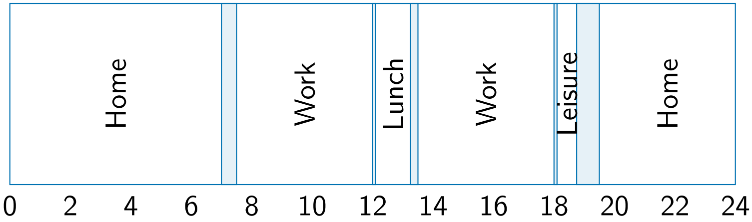
Modeling location choice

- “Dinner at home” and “dinner at a restaurant”
- are considered two different activities.
- Impose that maximum one of them is selected.

Modeling mode choice

- Having dinner and coming back by car or taxi
- are considered two different activities.
- Impose that maximum one of them is selected.

Scheduling



Categories

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

Category

Activities that share the same preference profile.

Preferences

Preferences

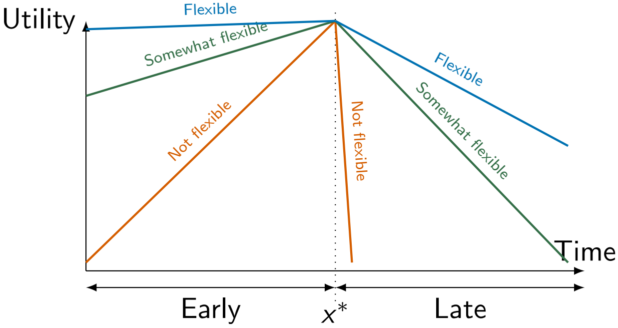
- desired starting time x_a^*,
- desired duration τ_a^*.

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 (time and cost) from a to a^+ negatively contributes to U_a: t_a, c_{t_a}.
- Exception: last activity of the day (home).

Utility function

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

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

where ξ_{an} is a random term with a known distribution.

Utility function

Error terms

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

Households

Assumptions

- Members of the households are altruist.
- Everybody makes decisions for the sake of the household.
- Objective function: sum of the utilities of each individual

Model

- Similar model as for individuals.
- Resource constraints can easily be added.

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

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

Constraints

Time budget

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

Cost budget

$$\sum_a c_a w_{anr} + t_{c_{anr}} = B, \ \forall n, r.$$

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

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

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

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Constraints

Travel time

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

Consistent timing

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

Mutually exclusive duplicates

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

Constraints

Interaction constraint

- If I leave home by bus, driving my car is not an option until I come back home.
- $\delta^{\text{car}}_{anr} = 1$ if car is available for activity a.

$$\delta^{\text{car}}_{anr} \geq \delta^{\text{car}}_{bnr} + z_{abnr} - 1.$$

Constraints

Resource constraints

- Resource (e.g. private vehicle) considered as an agent with a schedule.
- Maximum one activity at each time-step.
- Constraint: resource must be accompanied by an adult agent throughout the tour.
- Except when idling (vehicle at the parking at home).

Constraints: other examples

Participation constraints

- Participation constraints: if I drop the children off, somebody needs to pick them up later.
- Drop-off: activity a.
- Pick-up: activity b.
- Activity participation: $w_{bnr} \geq w_{anr}$
- Timing: $x_{bnr} \geq x_{anr}$.

Sequence constraints

- If I go grocery shopping I need to go back home before doing another activity.
- Shopping: activity a.
- Home: activity b.

$$z_{abnr} \geq w_{anr}.$$

Integrated framework

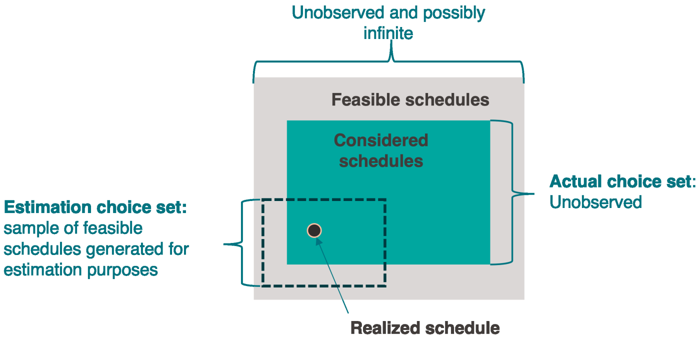
Mathematical programming

- Utility maximization.
- Scheduling problem.
- Rules are translated into additional constraints.
- Stochasticity is captured by simulation.

Outline

Challenges

- The universal choice set cannot be enumerated.
- Traditional maximum likelihood estimators of parameters cannot easily be derived.



Methodology

Choice set generation

- Importance sampling with Metropolis-Hastings algorithm
- Bias the sampling towards "good" or "meaningful" schedule.

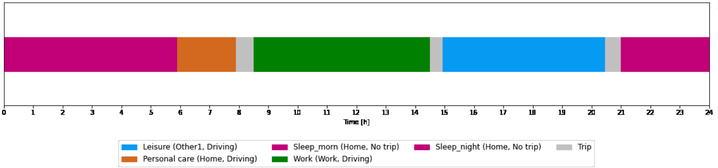
Parameter estimation

- Maximum likelihood estimation of a random utility model.
- Choice set contains only feasible schedules for individual n.
- Constraints can be ignored for inference.
- Need for correction for importance sampling [Guevara and Ben-Akiva, 2013].

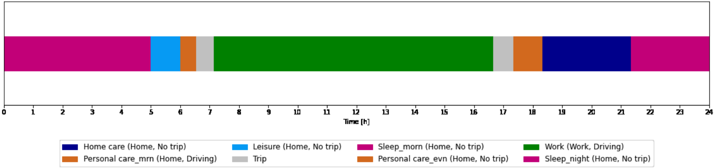
Outline

Simulation: From isolated individuals...

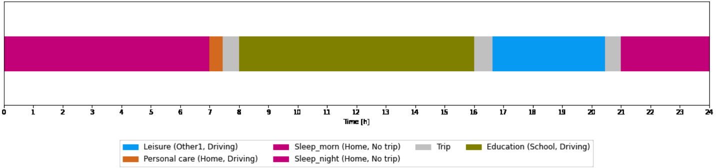
Sara



David

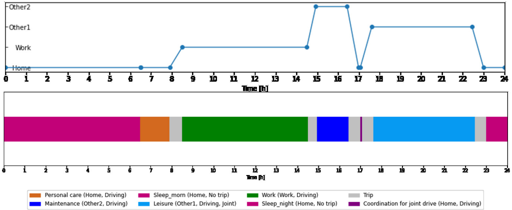


Alice

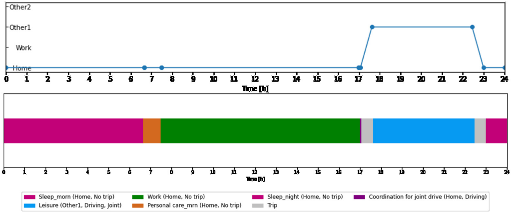


Simulation: To family of 2; 2 adults with no children...

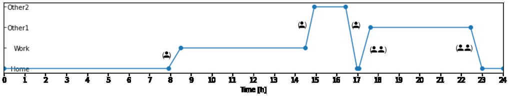
Sara



David



Car



Simulation: Family of 2; 2 adults with no children. . .

Table: Car location sequence and occupancy in the example of family of 2

Location	Start time (hh:mm)	End time (hh:mm)	Duration (hh:mm)	Person using	Parked_out indicator	Car occupancy
Home	00:00	7:54	7:54	-	0	0
On the road	7:54	8:30	0:36	1	0	1
Work	8:30	14:30	6:00	1	1	0
On the road	14:30	14:56	0:26	1	0	1
Other2	14:56	16:27	1:31	1	1	0
On the road	16:27	17:00	0:33	1	0	1
Home	17:00	17:05	0:05	-	0	0
On the road	17:05	17:38	0:33	1&2	0	2
Other1	17:38	22:27	4:49	1&2	1	0
On the road	22:27	23:00	0:33	1&2	0	2
Home	23:00	24:00	1:00	-	0	0

Simulation: To family of 3; 2 adults and 1 child. . .

Sara

David

Alice

Car

Simulation: Family of 3; 2 adults and 1 child

Table: Car location sequence and occupancy in the example of family of 3

Location	Start time (hh:mm)	End time (hh:mm)	Duration (hh:mm)	Person using	Parked_out indicator	Car occupancy
Home	00:00	7:12	7:12	-	0	0
On the road	7:12	7:45	0:33	1&3	0	2
School	7:45	7:47	0:02	1	0	1
On the road	7:47	8:15	0:28	1	0	1
Work	8:15	14:15	6:00	1	1	0
On the road	14:15	14:40	0:25	1	0	1
Other2	14:40	15:22	0:42	1	1	0
On the road	15:22	16:00	0:38	1	0	1
School	16:00	16:02	0:02	1	0	1
On the road	16:02	16:33	0:31	1&3	0	2
Home	16:33	24:00	7:27	-	0	0

Distributions

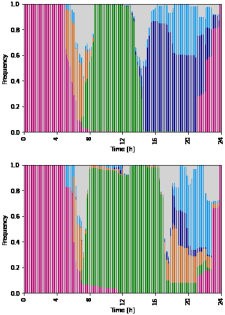
Figure: Isolated indiv.

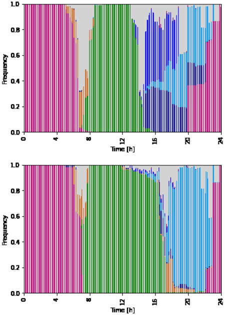
Figure: Family of 2

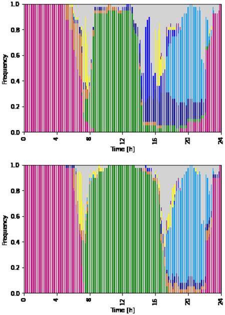
Figure: Family of 3

Sara

David





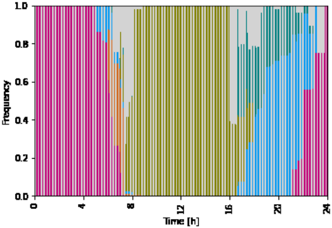


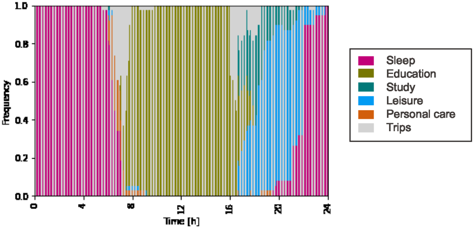
Distributions

Figure: Isolated individual

Figure: Family of 3

Alice





Schedule simulation

Data set

- 2015 Mobility and Transport Microcensus [ARE 2017]
- Nationwide travel survey conducted every 5 years
- Lausanne sample: 1118 individuals
  - Students: 236 individuals
  - Workers: 618 individuals

Example: model 1

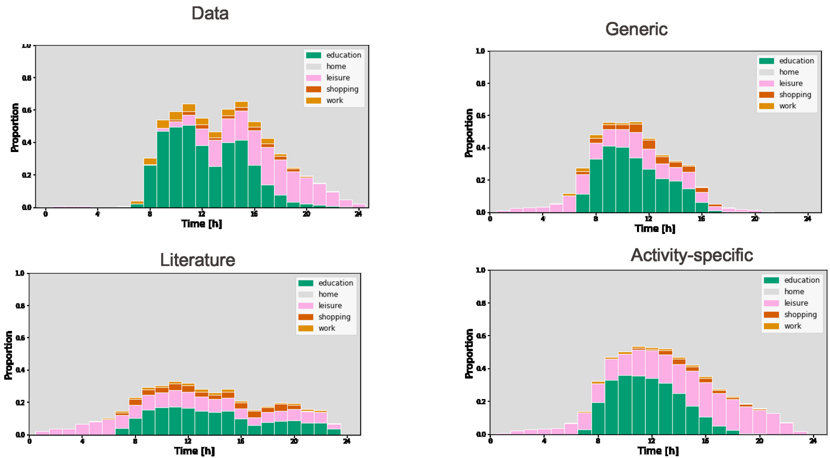
	Parameter	Param. estimate	Rob. std err	Rob. t-stat	Rob. p-value
1	F early	-0.175	0.12	-1.46	0.145
2	F late	-0.333	0.14	-2.38	0.0171
3	F long	-0.105	0.0722	-1.45	0.146
4	F short	-0.114	0.194	-0.585	0.559
5	NF early	-1.14	0.367	-3.10	0.00191
6	NF late	-0.829	0.229	-3.61	0.0003
7	NF long	-1.20	0.393	-3.05	0.00231
8	NF short	-1.19	0.468	-2.54	0.0011
9	ASC_Education	16.0	2.46	6.49	8.63e-11
10	ASC_Leisure	8.81	1.7	5.17	2.28e-07
11	ASC_Shopping	6.85	1.80	3.80	0.000146
12	ASC_Work	16.0	2.58	6.18	6.57e-10

Visual validation

Distribution of activities over the day

- Data: Swiss microcensus (validation sample).
- Literature: model with 8 parameters, borrowed from the literature.
- Generic: model with generic coefficients, estimated from data (previous slide).
- Activity-specific: model with a set of coefficients for each activity type, estimated from data (20 parameters).

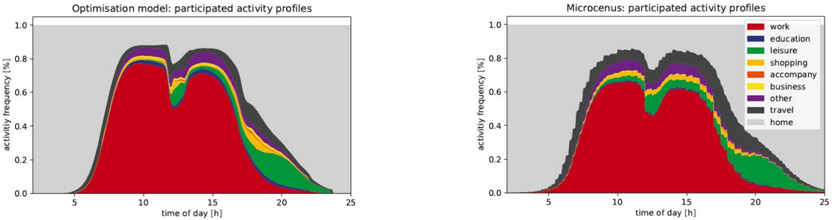
Visual validation



OPTIMs

OPTimization of **I**ndividual **M**obility **S**chedules, [Manser et al., 2021a]

- Collaboration with Swiss Federal Railways.
- Integration of the optimization framework into their long-term travel demand forecasting tool (SIMBA MOBi).



Conclusions

Achievements so far

- Formulation of the model.
- Procedure for the estimation of the parameters.
- Simulation of complex and valid activity schedules.
- Simulation of complex resources constraints.
- Simulation of household coordination.
- Application to real case studies.

Challenges

- Latent preferences (desired start times, durations...)
- Validation.

Summary

- Motivation: design operational activity-based models.
- Combine the econometric and the rule-based approaches.
- Methodological contribution: use mathematical programming and simulation.
- Simulation of activity schedule: [Pougala et al., 2022a].
- Application with the Swiss Railways: [Manser et al., 2021b].
- Estimation of the parameters: [Pougala et al., 2022b].
- Household interactions: under preparation.
- Main advantage of the framework: flexibility.

Summary

Long term research vision

- Synthetic population of households.
- Week-based activity scheduling.
- Real-time rescheduling.
- Applications to transportation and energy.

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