

# Modeling intra-household interactions and in-home activities in activity-based models

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March 13, 2023



# Outline

- 1 Motivation
- 2 Assumptions
- 3 Model
- 4 Parameter estimation
- 5 Applications





# Introduction

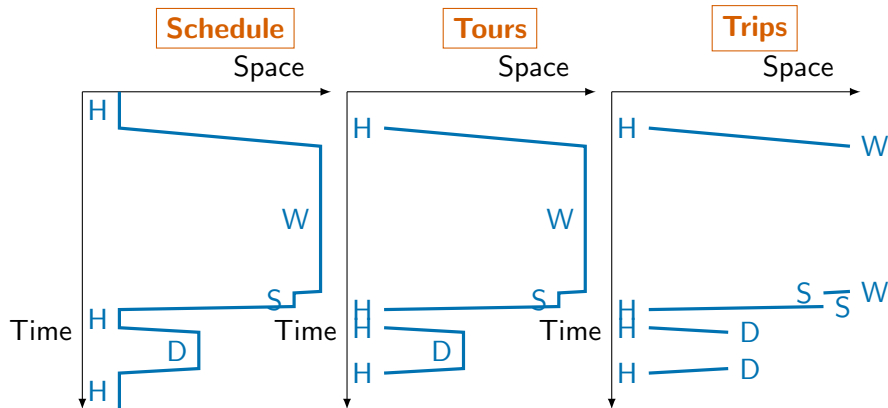


- Travel demand is derived from activity demand.
- Activity demand is influenced by socio-economic characteristics, social interactions, cultural norms, basic needs, etc. [Chapin, 1974]
- Activity demand is constrained in space and time [Hägerstrand, 1970].

## Activity-based models



# Travel demand models



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





# 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.





# 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.



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# 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.

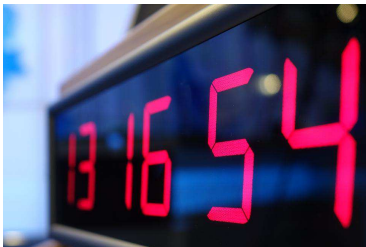
# Further assumptions



## 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.

# 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.

# 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

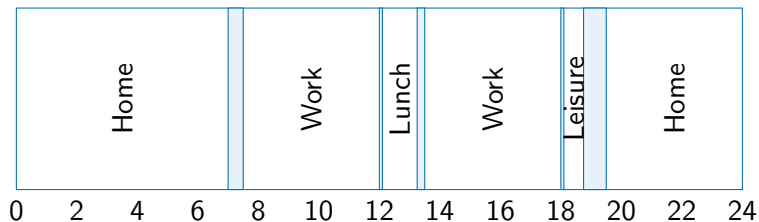
- “Dinner at home” and “dinner at a restaurant”
- are considered two different activities.
- Impose that maximum one of them is selected.

## 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  $\tau_a^*$ .

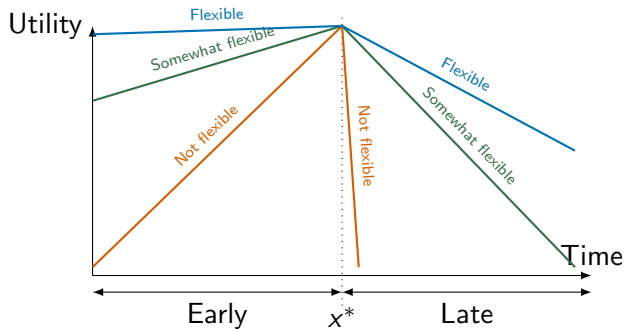
## Penalties

- 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  $k$ :

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

where  $\xi_{an}$  is a random term with a known distribution.

# Utility function



## Error terms

- Rely on simulation.
- Draw  $\xi_{anr}$ ,  $r = 1, \dots, R$ .
- 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.



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# Decision variables for individual $n$ and draw $r$

For each (potential) activity  $a$ :

- Activity participation:  $w_{anr} \in \{0, 1\}$ .
- Starting time:  $x_{anr} \in \{0, \dots, T\}$ .
- Duration:  $\tau_{anr} \in \{0, \dots, T\}$ .
- 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

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

## 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

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

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



# 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.
- $\delta_{anr}^{\text{car}} = 1$  if car is available for activity  $a$ .

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



# 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.



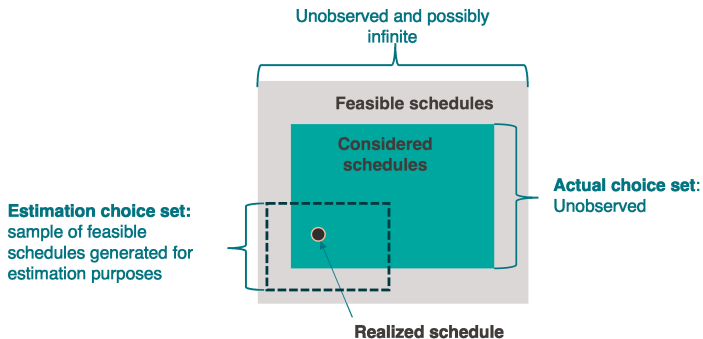
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# Challenges

- 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].

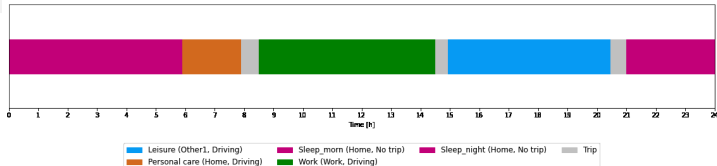
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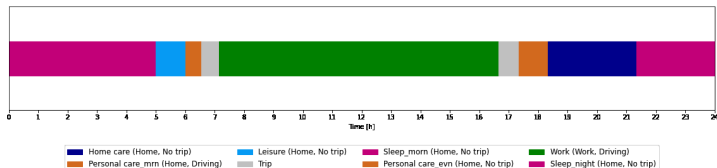


# Simulation: From isolated individuals...

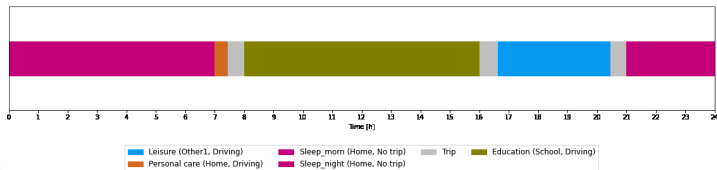
Sara



David



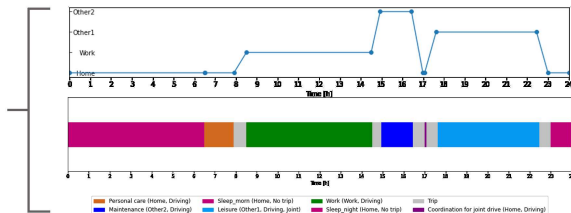
Alice



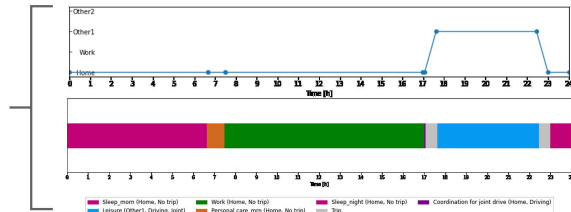


# Simulation: To family of 2; 2 adults with no children...

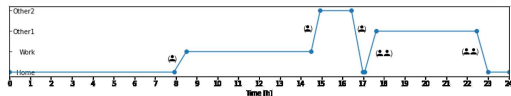
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David



Car



EPFL

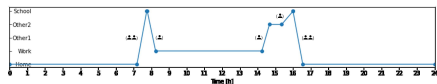
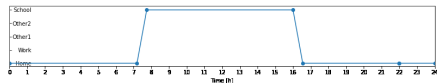
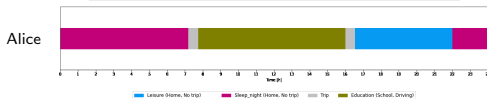
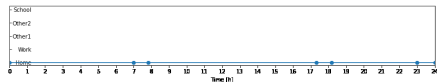
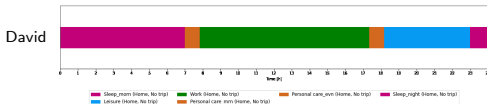
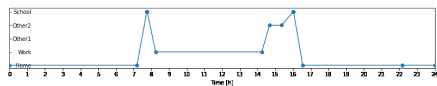
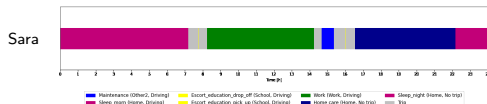
# Simulation: Family of 2; 2 adults with no children...

**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...



# 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



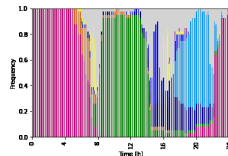
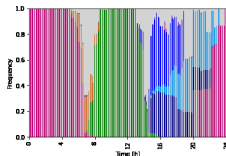
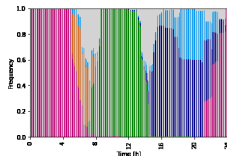
# Distributions

Figure: Isolated indiv.

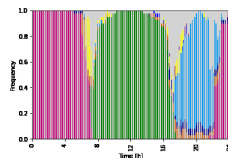
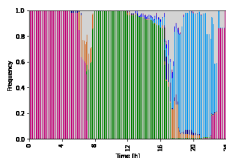
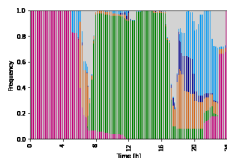
Figure: Family of 2

Figure: Family of 3

Sara



David



EPFL

# Distributions

Figure: Isolated individual

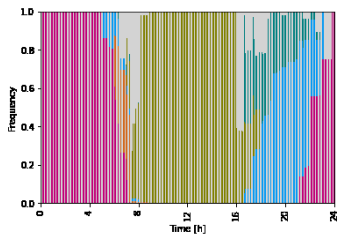
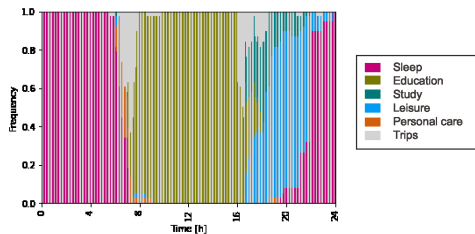


Figure: Family of 3



# 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. <i>t</i> -stat	Rob. <i>p</i> -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

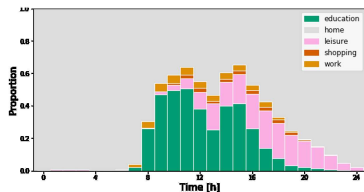
## Distribution of activities over the day

- 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).

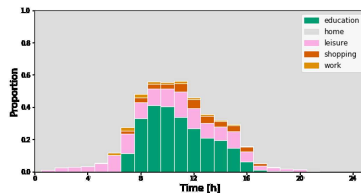


# Visual validation

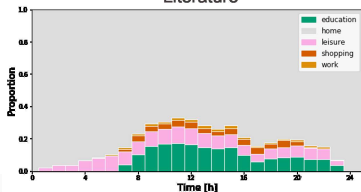
## Data



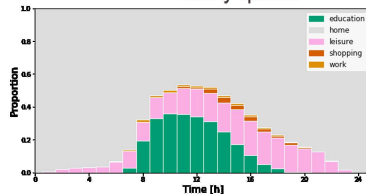
## Generic



## Literature



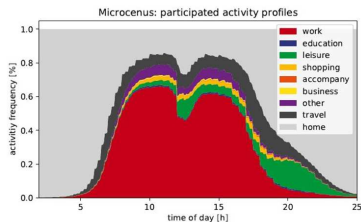
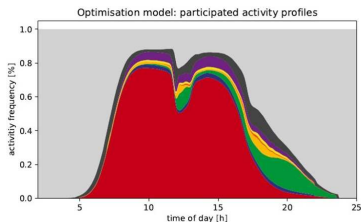
## Activity-specific



# OPTIMs

## OPTimization of Individual Mobility Schedules, [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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