Activity-based models: recent developments in travel demand modeling

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Outline

Introduction

Why do people travel?

- Most of the time, not for the sake of it.
- Activities.
- Spread in space and time.

Activities

Primary

- home-based,
- work,
- education.

Secondary

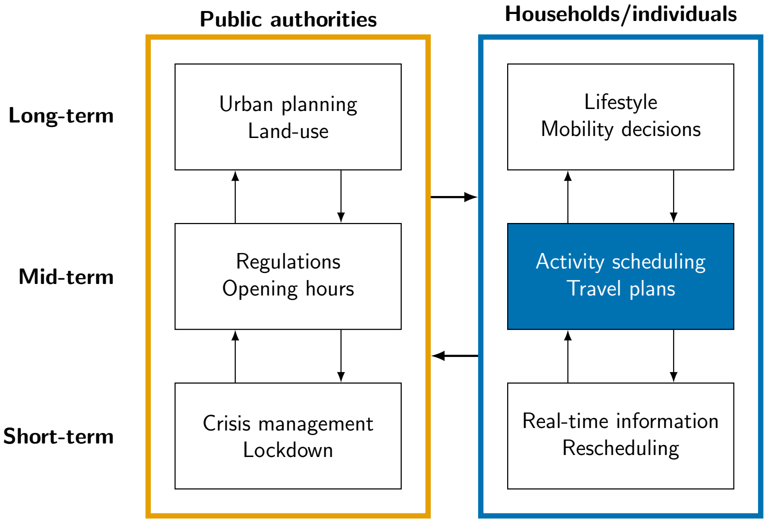
- leisure,
- shopping,
- escort,
- business,
- etc.

Travel demand

Combination of choices

- Choices of public authorities
- Choices of household/individuals
- Different time horizons

Choices and decisions



Model complexity

Granularity

- Time resolution
- Spatial discretization

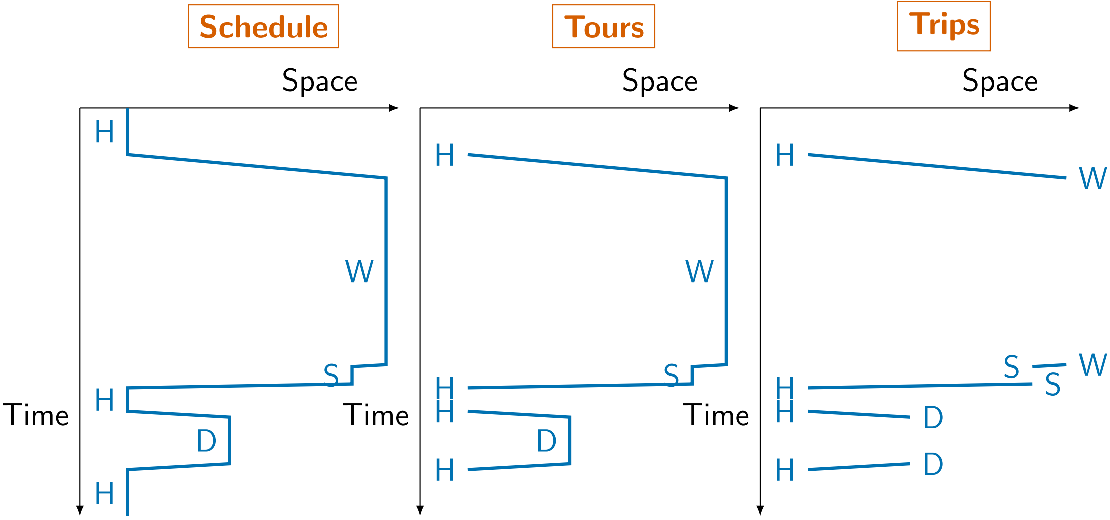
Level of aggregation

- Disaggregate: each individual
- Aggregate: flows

Travel patterns

- Activity schedules
- Tours
- Trips

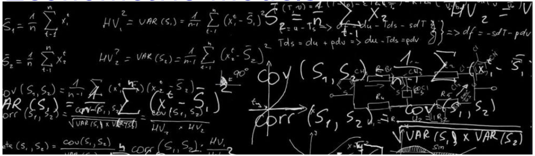
Travel demand models



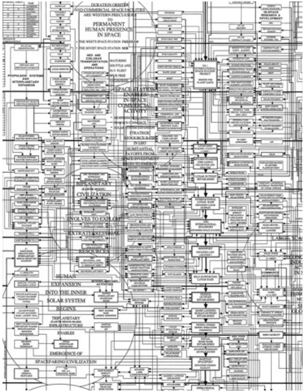
H: Home, W: Work, S: Shop, D: Dining out [Source: M. Ben-Akiva]

Activity-based models: 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 if it is parked at home.
  - Resource constraints: if my wife uses the only car in the household, driving the car is not an option for me unless we share rides.

Integrated approach

Mathematical optimization

- Each individual is solving an optimization problem.
- Decisions: activity participation, activity location, activity scheduling, travel mode, etc.
- Objective function: utility (to be maximized).
- Constraints: complex rules.

Challenges

- Stochasticity: random utility.
- Large number of variables and constraints.
- Large number of individuals.

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.

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 of the trip with mode m.
- For each (s_o, s_d): $\sigma^m(s_o, s_d)$ is the travel cost of the trip with mode m.
- Assumption: travel time and cost are exogenous.

Activities

Definition: Activity

The activity itself + a trip to the next one.

Activities

Activity a + trip to the next one

- Set A of activities.
- Location s_a.
- Transportation mode: m_a.
- Starting time x_a, $0 \leq x_a \leq T$.
- Duration: $\tau_a \geq 0$.
- Cost: c_a.
- Feasible time interval: $[\gamma_a^-, \gamma_a^+]$ (e.g. opening hours).

Activities

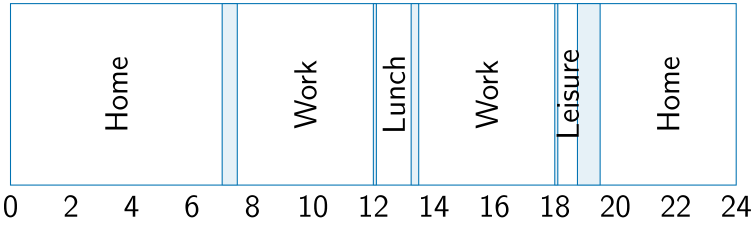
Modeling location choice

- "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

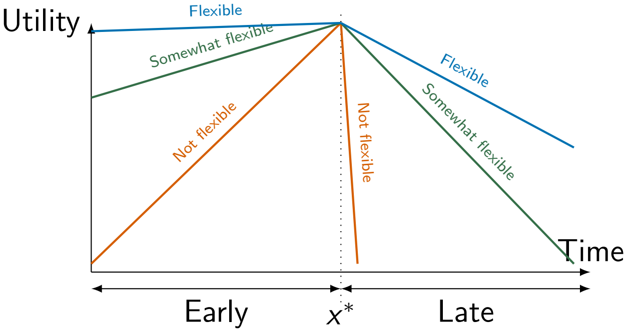
- desired starting time x_a^*,
- desired duration τ_a^*.

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.
- Exception: last activity of the day (home).

Utility function

An individual n derives the following utility from performing activity a:

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

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}.

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 from a to the next activity: t_{anr}.
- Travel cost from a to the next activity: $t_{c_{anr}}$.

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

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

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

Constraints

Travel time and cost

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

Mutually exclusive duplicates

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

Constraints

Consistent timing

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

Interaction constraint

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

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

Outline

Social groups

- Groups of individuals imply additional constraints.
- Coordination, joint activities.
- Group decision making
- Service to the group, maintenance.
- Resource constraints.
- Escorting.

Objective function: utility of the group

Group decision making

- Function of the utility of each member. But which function?
- Lack of consensus in the literature.
- Additive: the (weighted) sum of the utility of each member.
- Autocratic: the utility of the "strongest" member.
- Egalitarian: the utility of the "weakest" member.
- Important for our framework: must be easy to linearize.

Constraints

Coordinated activities

- a is an activity that must be performed by all members of the group.
- Dining out.
- Family gathering.
- Sport events.
- Activity participation of the group: w_{agr}.

$$\sum_{n \in g} w_{anr} = N_g w_{agr}.$$

Constraints

Distributed activities

- a is an activity that must be performed for the group.
- Maintenance.
- Grocery shopping.
- Meal preparation.
- Accounting of the sport club.

$$\sum_{n \in g} w_{anr} \geq 1.$$

Constraints

Resource constraints

- One car per household.
- One meeting room in a shared office space.
- Modeling approach: treat the resource as an individual.
- “The car is a member of the family”.
- It is associated with “activities” and a schedule.
- We can then introduce “coordinated activities” constraints.

Constraints

Escorting a child to school

- Specific instance of a resource constraint.
- The person escorting becomes a resource.
- As individuals and resources are modeled in the same way, coordinated activities constraints can be applied.

Mathematical optimization framework

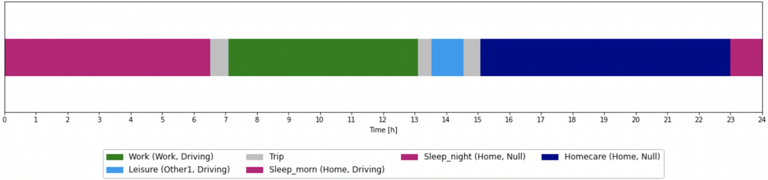
Combining rule-based and econometric approaches

- Works well for the simulation of individuals decisions.
- Can easily be extended for social groups.
- Most "rules" can be translated into relatively simple mathematical constraints.
- Main issue: choice of the objective function.

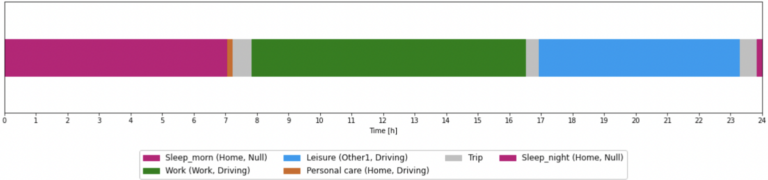
Outline

Simulation: From isolated individuals. . .

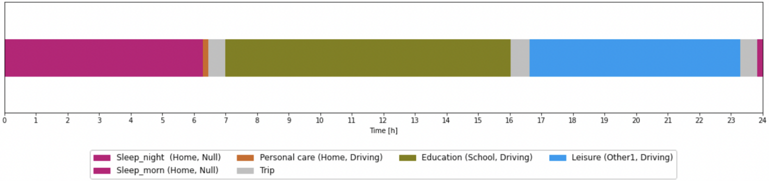
Sara



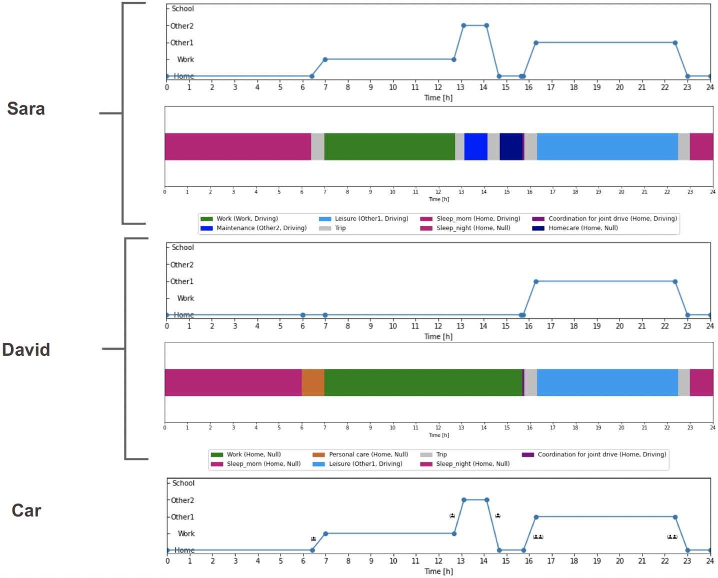
David



Alice



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



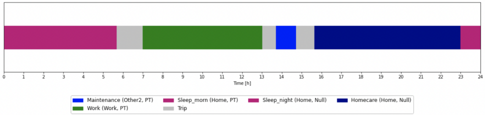
Simulation: Family of 2; 2 adults with no children...

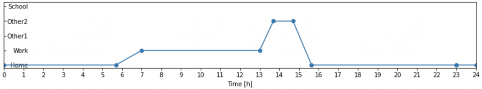
Table: Car location sequence and occupancy in the example of a family of 2

Location	Start time (hh:mm)	End time (hh:mm)	Duration (hh:mm)	Person using	Parked_out indicator	Car occupancy
Home	00:00	6:24	6:24	-	0	0
On the road	6:24	7:00	0:36	1	0	1
Work	7:00	12:41	5:41	1	1	0
On the road	12:41	13:07	0:26	1	0	1
Other2	13:07	14:07	1:00	1	1	0
On the road	14:07	14:40	0:33	1	0	1
Home	14:40	15:45	1:05	-	0	0
On the road	15:45	16:18	0:33	1 & 2	0	2
Other1	16:18	22:27	6:08	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

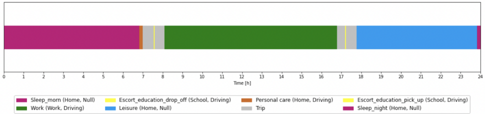
Simulation: To family of 3; 2 adults and 1 child...

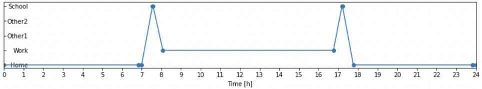
Sara



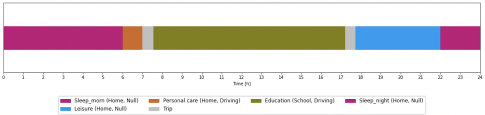


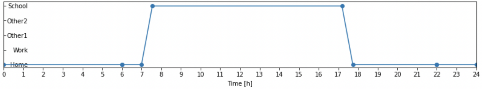
David



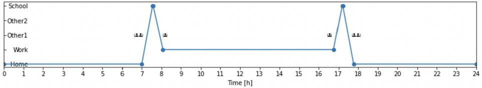


Alice





Car

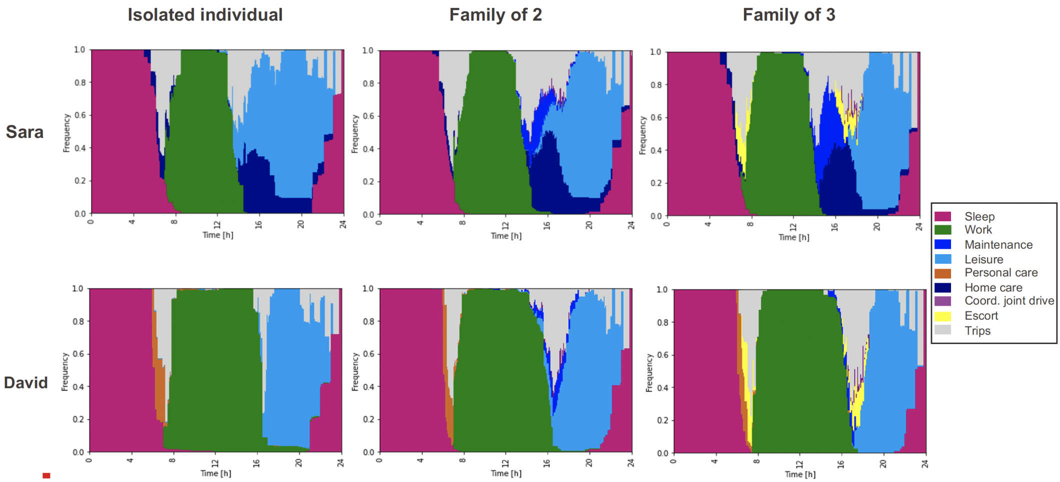


Simulation: Family of 3; 2 adults with 1 child...

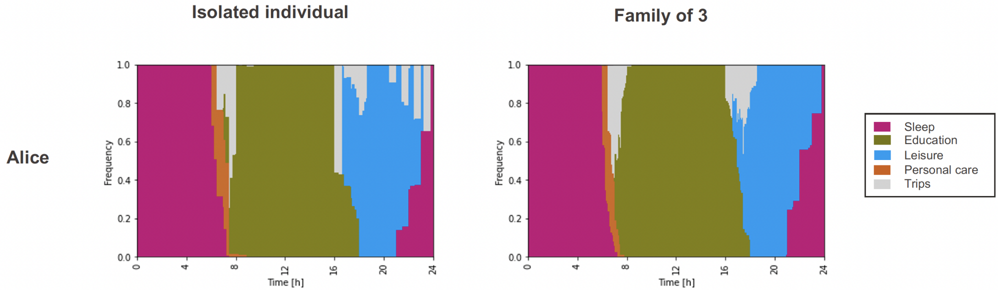
Table: Car location sequence and occupancy in the example of a family of 3

Location	Start time (hh:mm)	End time (hh:mm)	Duration (hh:mm)	Person using	Parked_out indicator	Car occupancy
Home	00:00	7:00	7:00	-	0	0
On the road	7:00	7:33	0:33	2 & 3	0	2
School	7:33	7:35	0:02	2	0	1
On the road	7:35	8:05	0:30	2	0	1
Work	8:05	16:45	8:40	2	1	0
On the road	16:45	17:11	0:26	2	0	1
School	17:11	17:13	0:02	2	1	1
On the road	17:13	17:46	0:33	2 & 3	0	2
Home	17:46	24:00	6:14	-	0	0

Distributions



Distributions



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

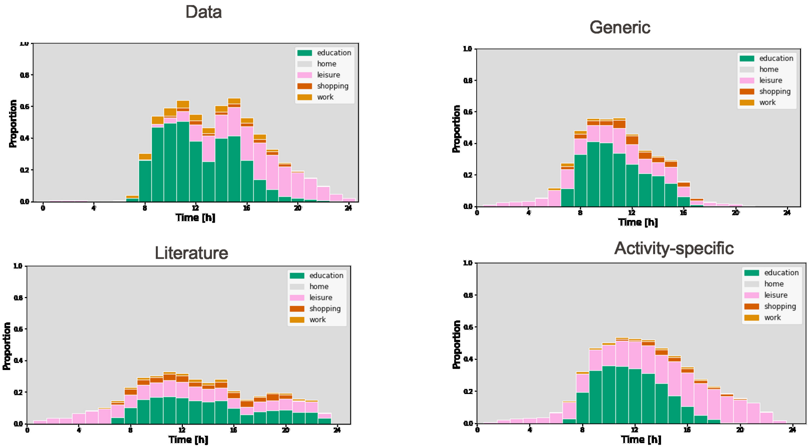
	Parameter	Param. estimate	Rob. std err	Rob. *t*-stat	Rob. *p*-value
1	F early	-0.175	0.12	-1.46	0.145
2	F late	-0.333	0.14	-2.38	0.0171
3	F long	-0.105	0.0722	-1.45	0.146
4	F short	-0.114	0.194	-0.585	0.559
5	NF early	-1.14	0.367	-3.10	0.00191
6	NF late	-0.829	0.229	-3.61	0.0003
7	NF long	-1.20	0.393	-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).

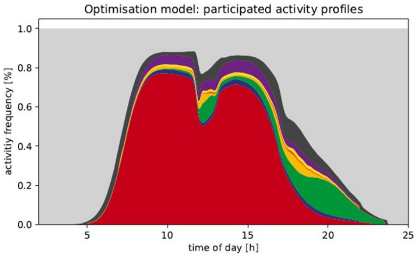
Visual validation

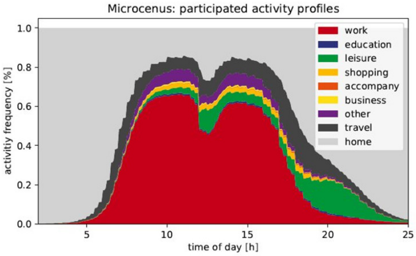


OPTIMs

OPTimization of **I**ndividual **M**obility **S**chedules,[Manser et al., 2022]

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





Conclusions

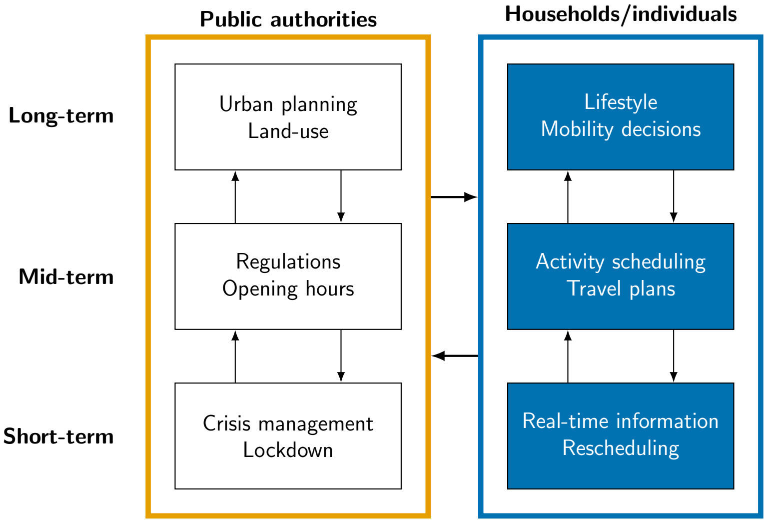
Achievements so far

- 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.

Summary

- Motivation: design operational activity-based models.
- Combine the econometric and the rule-based approaches.
- Methodological contribution: use mathematical optimization and simulation.
- Simulation of activity schedule: [Pougala et al., 2022a].
- Application with the Swiss Railways: [Manser et al., 2021].
- Estimation of the parameters: [Pougala et al., 2022b].
- Household interactions: [Rezvany et al., 2023], [Rezvany et al., 2024].
- Main advantage of the framework: flexibility.

Long-term research vision



Long term research vision

Long-term

- Synthetic populations.
- Synthetic households.
- Dynamic synthetic populations.

Mid-term

- Week-based activity scheduling.
- Latent preferences (desired start times, durations...)
- Applications to energy.

Short-term

- Real-time rescheduling.
- Integration with assignment models and agent-based simulation.

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