Activity-based models: an optimization approach

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November 13, 2024

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

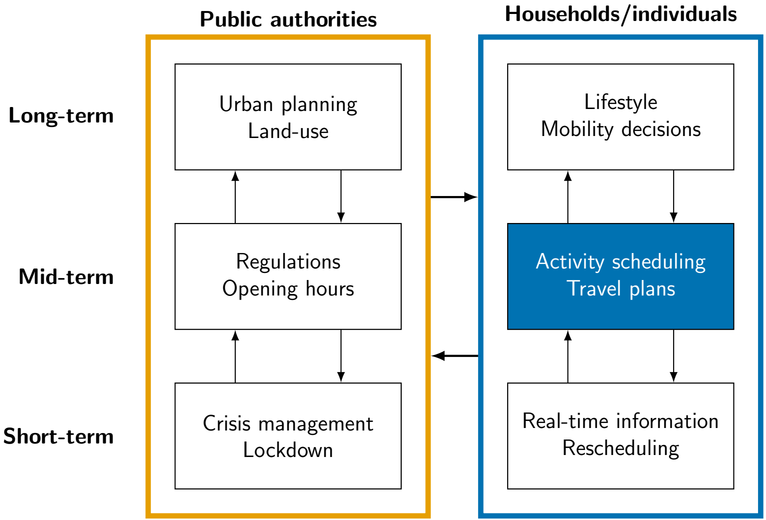
- leisure,
- shopping,
- escort,
- business,
- etc.

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

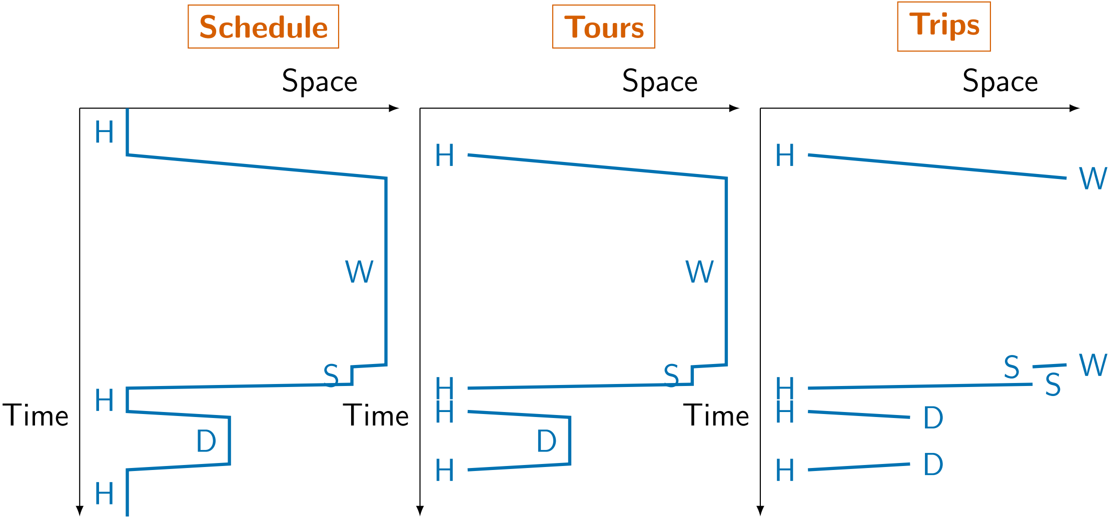
Level of aggregation

- Disaggregate: each individual
- Aggregate: flows

Travel patterns

- Activity schedules
- Tours
- Trips

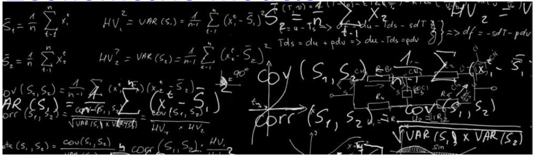
Travel demand models



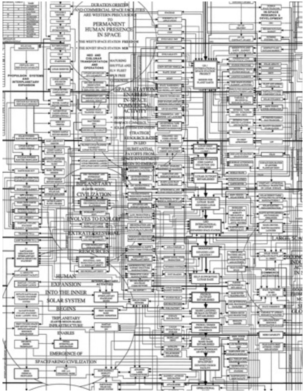
H: Home, W: Work, S: Shop, D: Dining out [Source: M. Ben-Akiva]

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

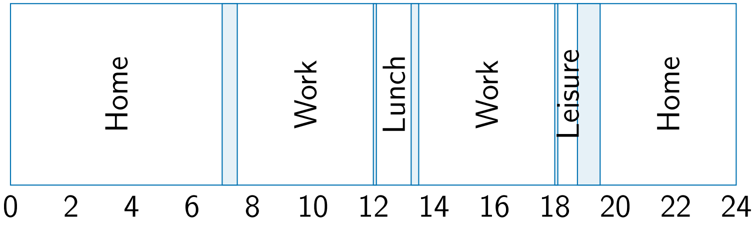
Modeling location choice

- "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

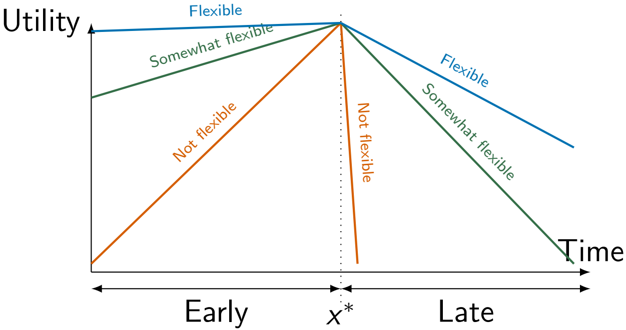
- desired starting time x_a^*,
- desired duration τ_a^*.

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

Motivation

Assumptions

Model

Social groups

Applications

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.

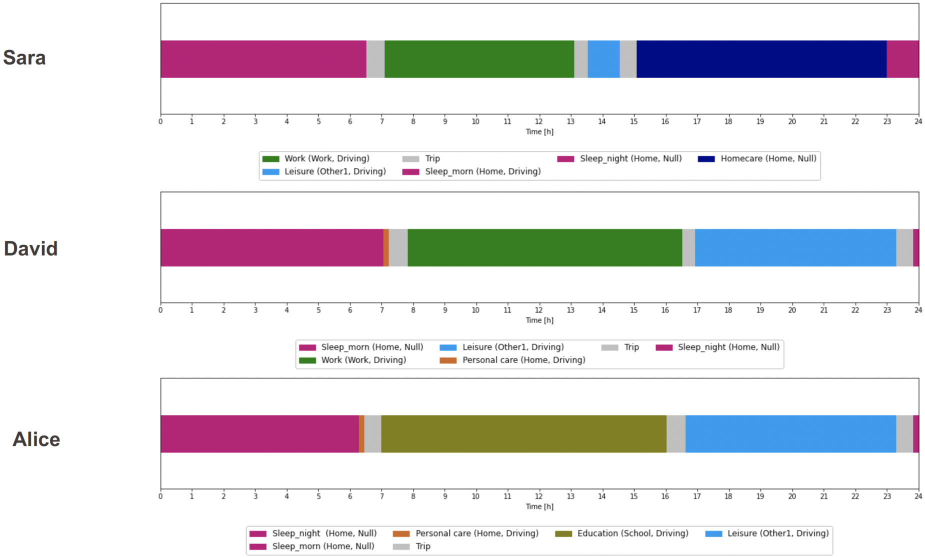
Mathematical optimization framework

Combining rule-based and econometric approaches

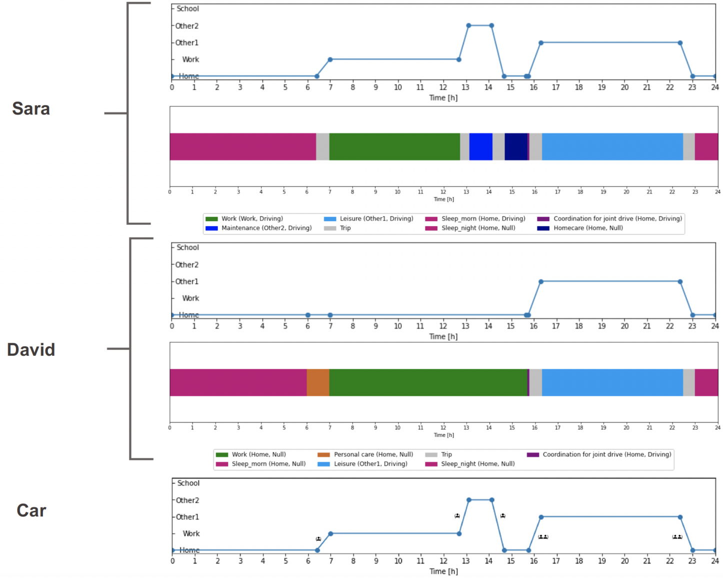
- Works well for the simulation of individuals decisions.
- Can easily be extended for social groups.
- Most “rules” can be translated into relatively simple mathematical constraints.
- Main issue: choice of the objective function.

Outline

Simulation: From isolated individuals. . .



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



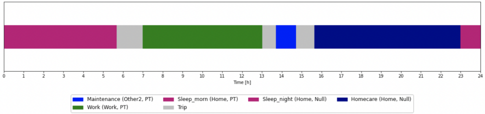
Simulation: Family of 2; 2 adults with no children...

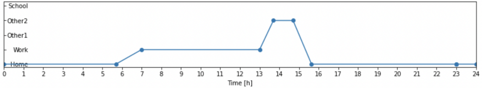
Table: Car location sequence and occupancy in the example of a family of 2

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

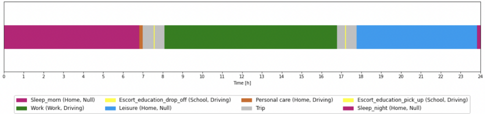
Simulation: To family of 3; 2 adults and 1 child...

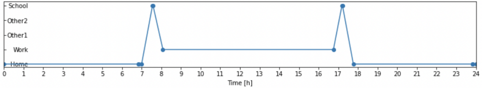
Sara



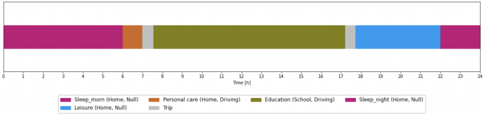


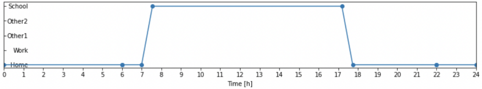
David



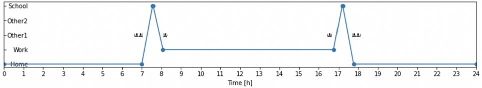


Alice





Car

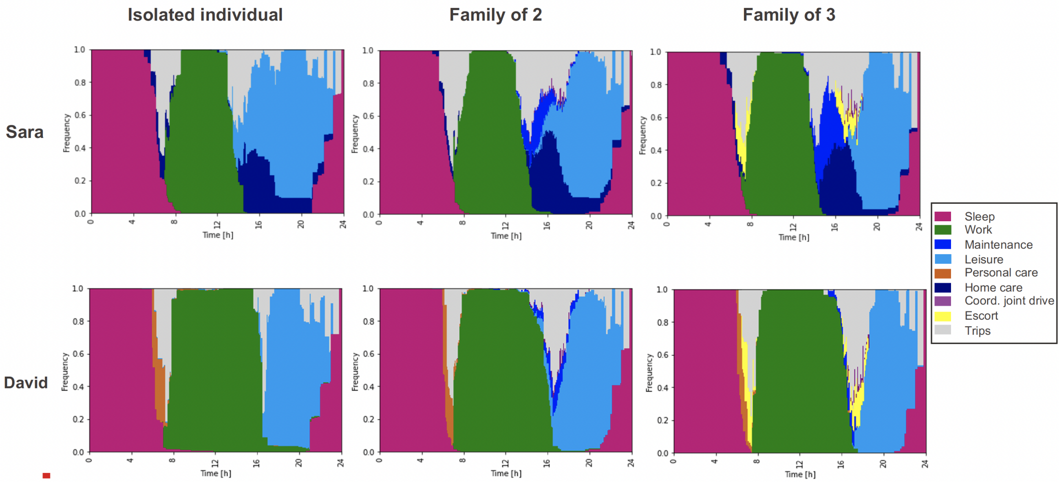


Simulation: Family of 3; 2 adults with 1 child...

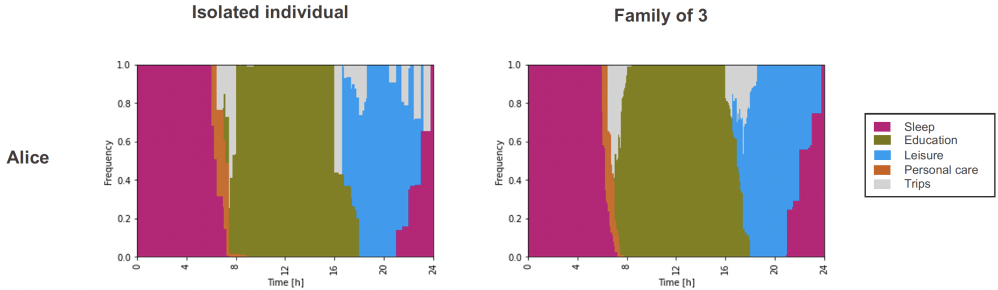
Table: Car location sequence and occupancy in the example of a family of 3

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

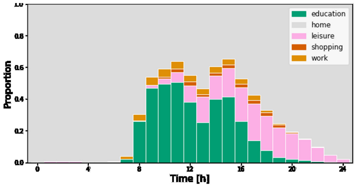
Visual validation

Distribution of activities over the day

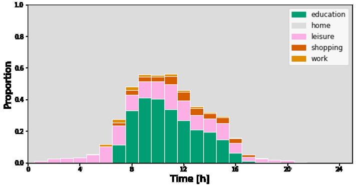
- Data: Swiss microcensus (validation sample).
- Literature: model with 8 parameters, borrowed from the literature.
- Generic: model with generic coefficients, estimated from data (previous slide).
- Activity-specific: model with a set of coefficients for each activity type, estimated from data (20 parameters).

Visual validation

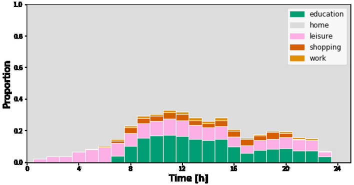
Data



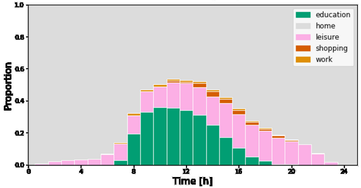
Generic



Literature



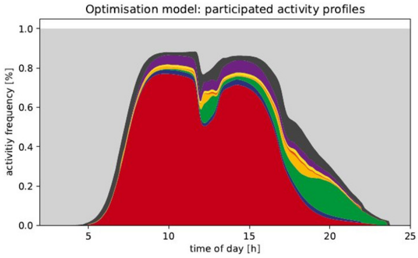
Activity-specific

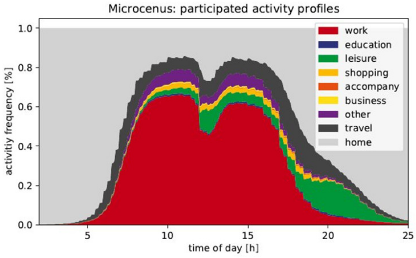


OPTIMs

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

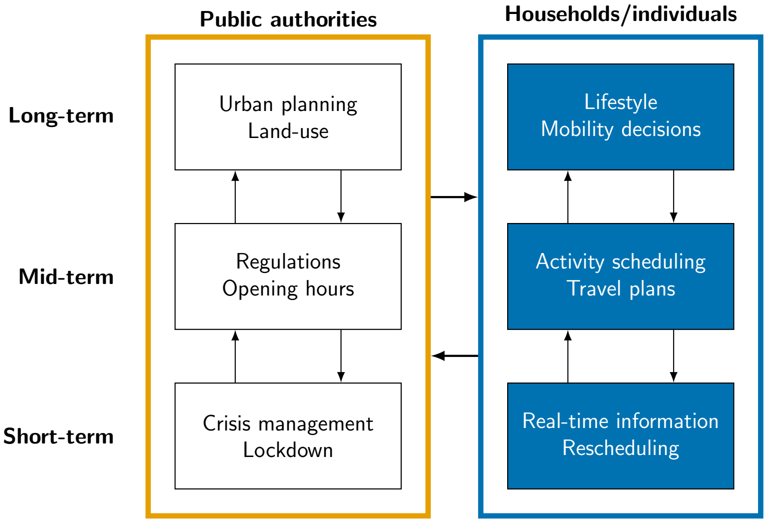
Achievements so far

- 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.

Bibliography I

- ARE: Office fédéral de la statistique and Office fédéral du développement Territorial (2017).
  Comportement de la population en matière de transports. Résultats du microrecensement mobilité et transports 2015.
  Technical report, Neuchâtel, Berne.

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

- Manser, P., Haering, T., Hillel, T., Pougala, J., Krueger, R., and Bierlaire, M. (2021).
  Resolving temporal scheduling conflicts in activity-based modelling.
  Technical Report TRANSP-OR 211209, Lausanne, Switzerland.

Bibliography II

Manser, P., Haering, T., Hillel, T., Pougala, J., Krueger, R., and Bierlaire, M. (2022).
Estimating flexibility preferences to resolve temporal scheduling conflicts in activity-based modelling.
Transportation.
Accepted on Aug 22, 2022.

Pougala, J., Hillel, T., and Bierlaire, M. (2022a).
Capturing trade-offs between daily scheduling choices.
Journal of Choice Modelling, 43(100354).
Accepted on Mar 19, 2022.

Bibliography III

- Pougala, J., Hillel, T., and Bierlaire, M. (2022b).
  Oasis: Optimisation-based activity scheduling with integrated simultaneous choice dimensions.
  Technical Report TRANSP-OR 221124, Transport and Mobility Laboratory, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.

- Rezvany, N., Bierlaire, M., and Hillel, T. (2023).
  Simulating intra-household interactions for in- and out-of-home activity scheduling.
  Transportation Research Part C: Emerging Technologies, 157(104362).
  Accepted on Sep 26, 2023.

Bibliography IV

Rezvany, N., Hillel, T., and Bierlaire, M. (2024).
Household-level choice-set generation and parameter estimation in activity-based models.
Technical report, Transport and Mobility Laboratory, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.

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