EPFL

TRANSP-OR

Integrated in- and out-of-home scheduling framework:
A utility optimization-based approach

Negar Rezvany

Tim Hillel

Michel Bierlaire

Outline

- **Introduction and motivation**
  - Why is studying activity scheduling throughout the day important?

- **Current literature and limitations**
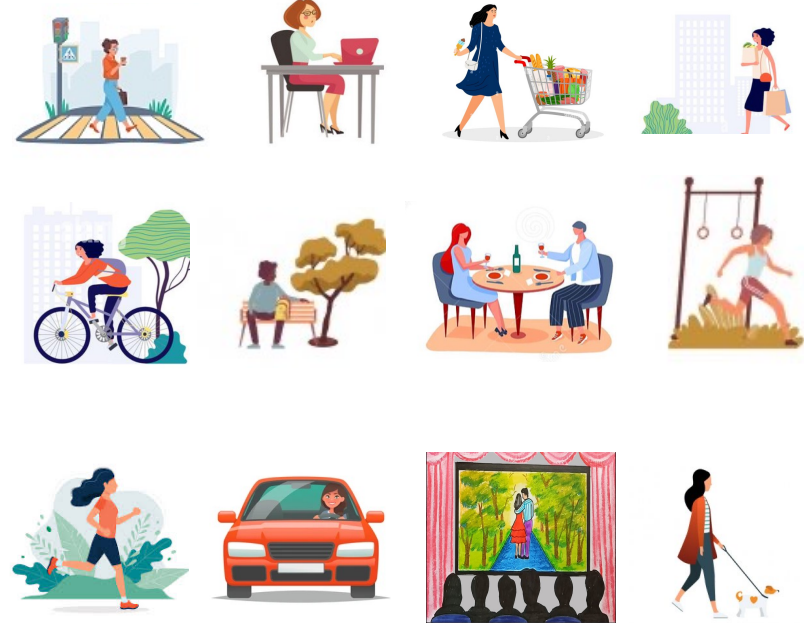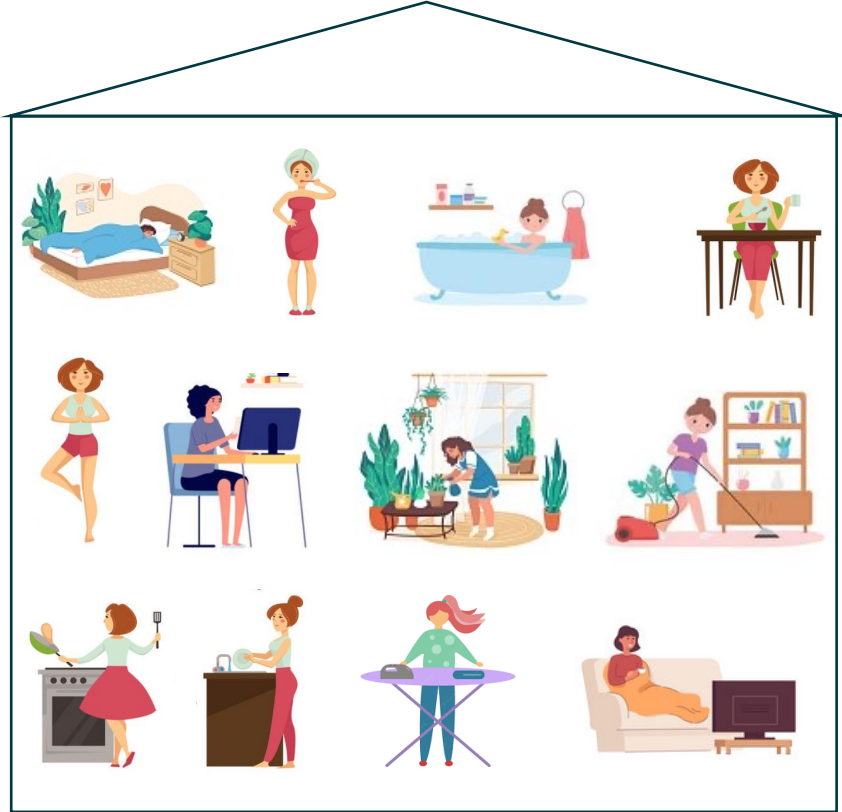 - What are the current research streams in activity-based modeling?

- **Model framework**
  - What are the differences between scheduling activities in-home and out-of-home?

- **Empirical investigation**

- **Results**

- **Further research**

Motivation and possible applications
Why is studying activity scheduling throughout the day important?

1. It allows modellers to capture the **trade-offs and interactions** between in-home and out-of-home activities
   - Squeezing in-home activities when spending more time on out-of-home activities
   - Deciding where to do different activities; at home or at an out-of-home location; based on the schedule of the whole day

2. This modeling approach can contribute to **demand side management**
   - Energy and transport demand can both be considered as being derived from an individual's activity participation
   - Activity scheduling is the connecting element between transportation and energy simulation
   - Time-use pattern inside home can be used to predict building energy demand at high temporal resolution

Major research streams in Activity-based models
What are the current research streams in activity-based modeling?

Limitations of the current models
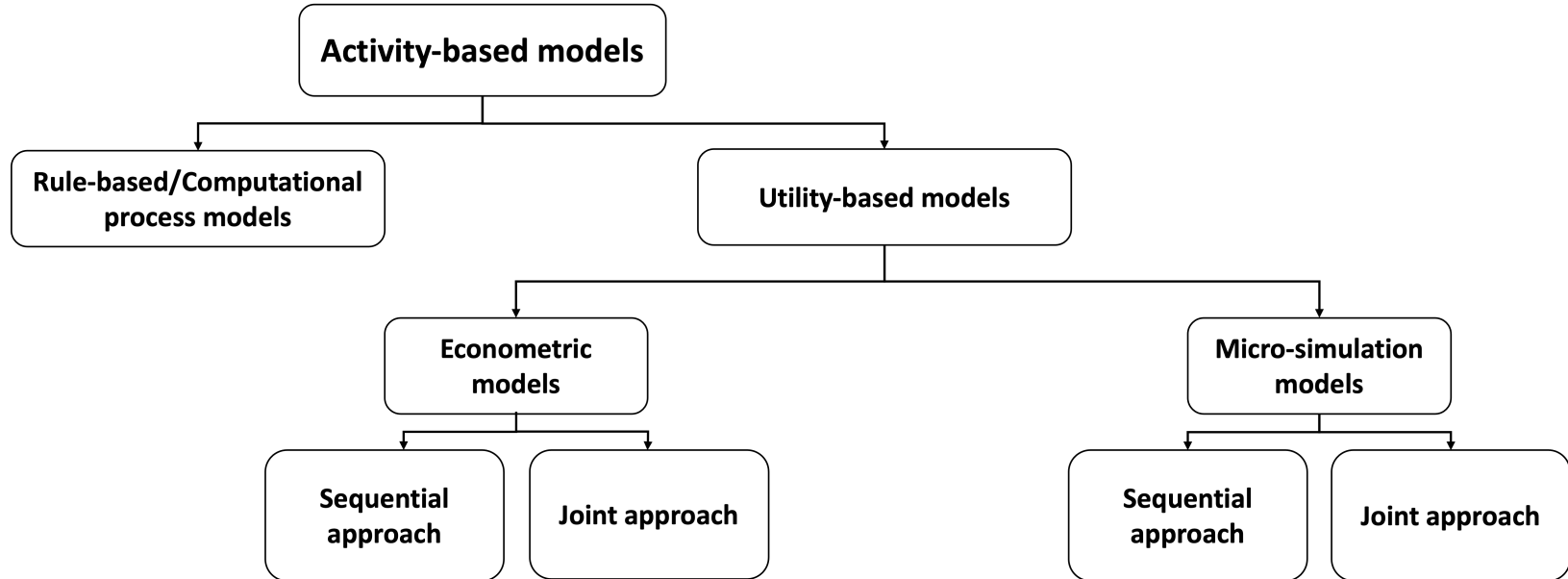
- **Methodological:**
  - Empirical rule-based or randomized process to determine individuals' activity scheduling
    - Hard-coded and cannot be generalised to situations not seen in the data
    - Do not represent the nature of scheduling process and cannot capture complex trade-offs and household interaction

- **Contextual:**
  - The current approaches to simulate the activity patterns focus on either time-use in home or out-of-home activities and **not both**
    - Thus, the interactions between in- and out-of-home activities (e.g., squeezing in-home activities when spending more time on out-of-home activities) are not considered

Utility-based optimisation model (*Pougala et al., 2021*)

ω_{in}: indicate activity participation (0/1)

$$\Omega_n = max \sum_i \omega_{in} U_{in}$$

Individual n

Activity i

- In order to address these shortcomings, *Pougala et al. (2021)* proposes a new scheduling framework:
  - Treats *individuals* as *utility maximizers*
  - Defined as a mixed-integer optimization problem for each *individual*, maximising the sum of the utilities of completed activities in a schedule over a fixed time budget
  - Incorporates *simultaneous estimation* of multiple scheduling decisions such as activity participation, and activity scheduling (start time, duration, sequence)
  - Generates distribution of schedules from which likely schedules can be stochastically drawn
  - **Output:** a feasible schedule
  - **Major advantages:** high level of flexibility, explicit constraints, simultaneous estimation of scheduling decisions
  - **Possible gaps for extension:**
    - the framework has been investigated only for studying the out-of-home activity scheduling (developed for transportation models) → the resulting schedules do not contain any information on activities performed at home

Utility formulation

$$U_{in} = U_{\text{const},in} + U_{\text{timing},in} + U_{\text{duration},in} + U_{\text{tt},in} + \varepsilon_{in}$$

- $U_{const,in}$: A constant utility of activity participation
- $U_{timing,in}$: capture the impact of schedule deviations (start times) on the total utility
- $U_{duration,in}$: capture the impact of schedule deviations (duration) on the total utility
- $U_{tt,,in}$: represent the utility of travelling to the location of the activity
- ε_{in} : random term

Model framework

$$\Omega_n = max \sum_i \omega_{in} U_{in}$$

ω_{in}: indicate activity participation (0/1)

Individual n

Activity i

- Build on the scheduling model developed by *Pougala et al. (2021)*
- Extend the framework to:
  - Incorporate joint modelling of time-use in the home alongside activities outside the home
  - Incorporates simultaneous estimation of choice of activity location as well as other scheduling decisions

What are the differences between scheduling activities in-home and out-of-home?

Out-of-home activities

In-home activities

- Hard time-window constraints
- Mostly more sensitive to schedule deviations
- Include trips and mode choice

- Time budget

- Soft time-window constraints
- Mostly more flexible to schedule deviations
- No trips
- Space and resource constraints explicitly affect household members' schedules
- Interactions within household members

Empirical investigation

Dataset
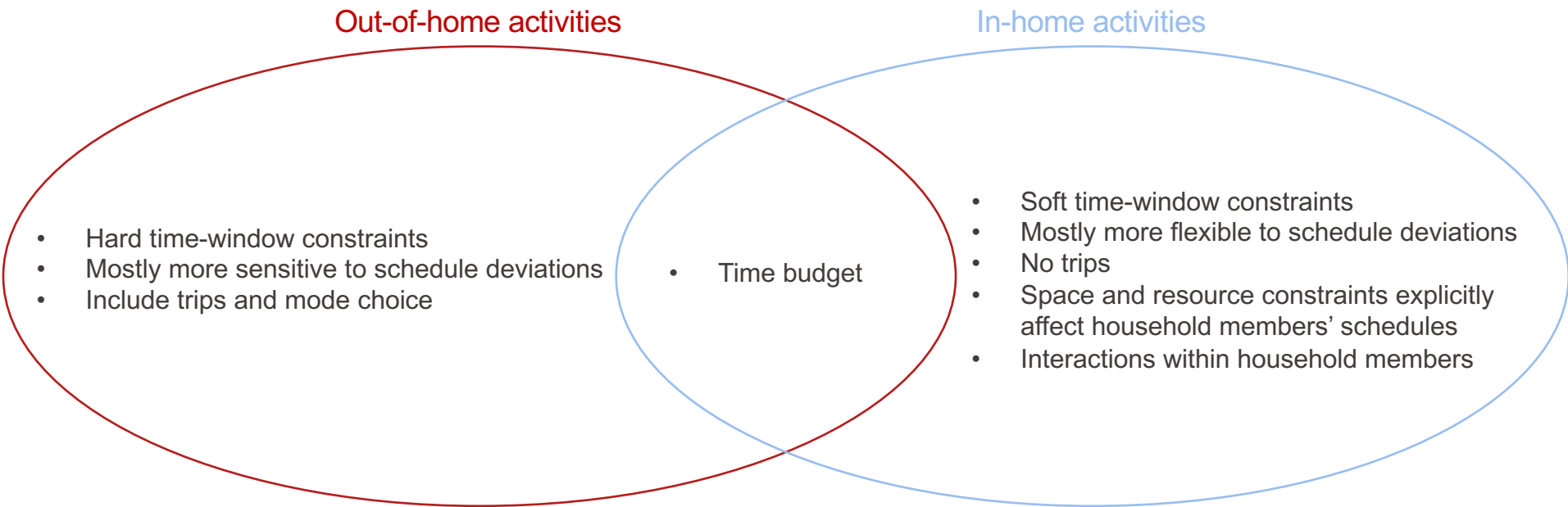
CaDDI* survey: 2016-2020 UK TUS Pre- and During Covid-19 Social Restrictions (Gershuny & Sullivan, 2021)

- A sequence of **online** time-use diary surveys designed to capture daily behavior throughout the various stages of the pandemic in the UK

- **4'360** diaries from **2'202** individuals across 4 waves

- *4 waves* (2016 & late May-June, August, November 2020)

full lockdown

second lockdown
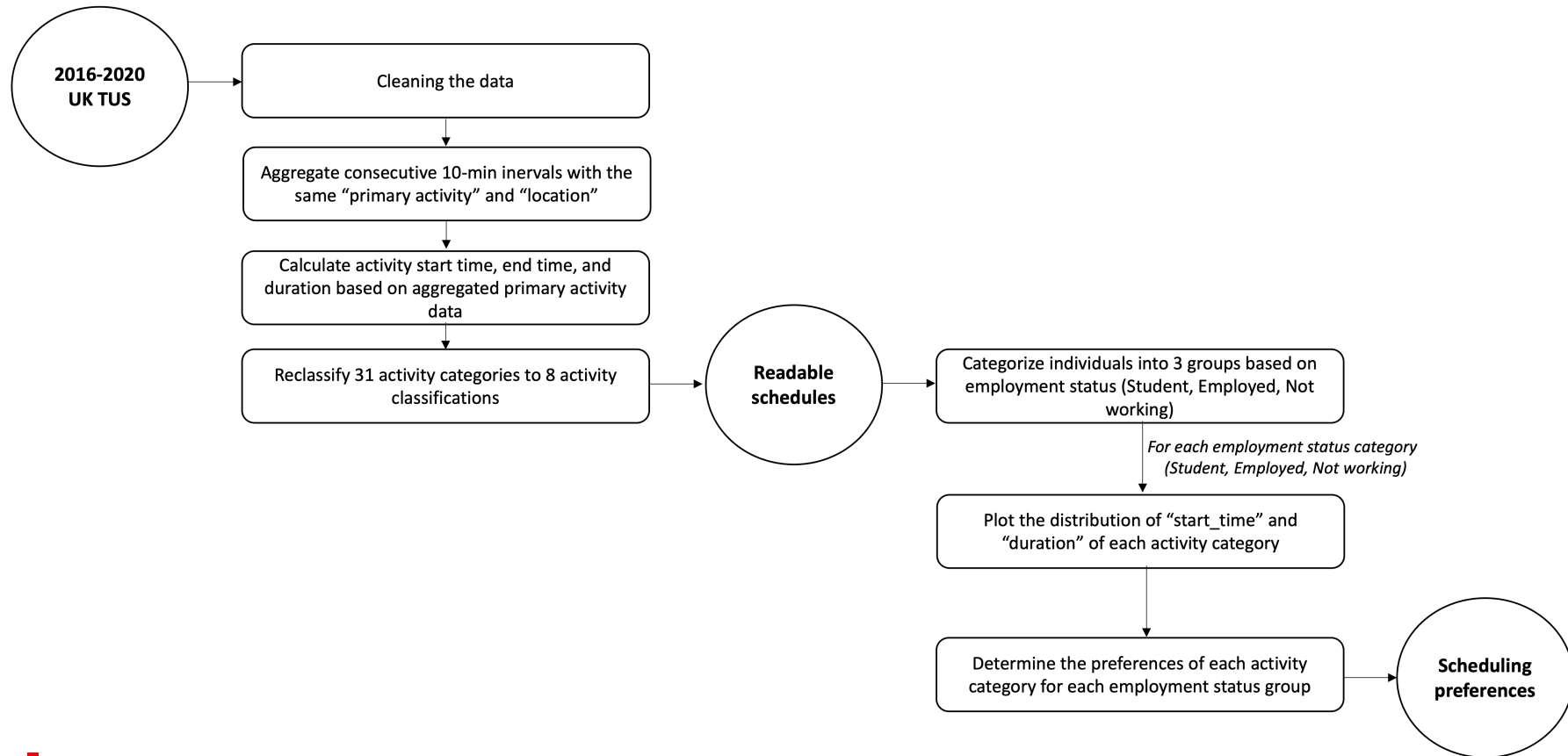
during the easing of social restrictions

- Contains **1 to 3** time-use diaries per respondent (include 1 weekday and 1 weekend day)

- Includes information on **socio-demographic** variables, **activities**, **location**, **device use**, **enjoyment**, and **co-presence**
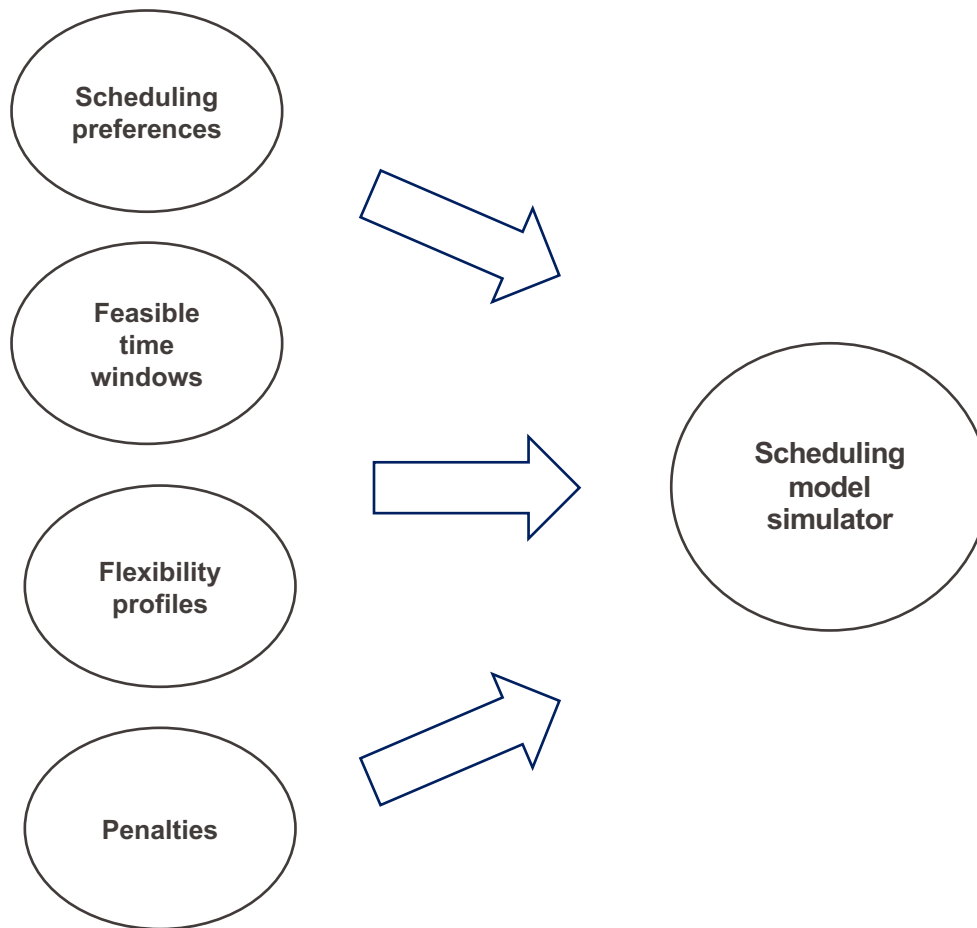
- * Click and drag diary

Data pre-process

	mainid	survey	dday	econstat	pri1	pri2	pri3	pri4	pri5	pri6	...	pri135	pri136	pri137	pri138	pri139	pri140	pri141	pri142	pri143	pri144	loc1	loc2	loc3	loc4	loc5	loc6	...	loc135	loc136	loc137	loc138	loc139	loc140	loc141	loc142	loc143	loc144
0	47	1.0	3	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
1	47	1.0	6	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	203	203	203	203	203	203	203	203	203	203
2	62	1.0	1	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
3	62	1.0	7	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
4	69	1.0	1	10	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4355	41766	4.0	3	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
4356	41766	4.0	4	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
4357	41769	4.0	7	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
4358	41771	4.0	1	3	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201
4359	41772	4.0	5	5	101	101	101	101	101	101	...	101	101	101	101	101	101	101	101	101	101	201	201	201	201	201	201	...	201	201	201	201	201	201	201	201	201	201

	mainid	dday	act_id	loc_id	location	act_label	label	start_time	end_time	duration
0	47	3	101	201	Home	Sleeping	Sleep	4.000000	6.333333	2.333333
1	47	3	103	201	Home	Washing, dressing	Personal care	6.333333	7.000000	0.666667
2	47	3	121	201	Home	Caring for own child	Home care	7.000000	8.500000	1.500000
3	47	3	111	203	Other	Walking, Jogging	Trips	8.500000	10.000000	1.500000
4	47	3	117	202	Work	Paid work	Work	10.000000	13.000000	3.000000
...	...	...	...	...	...	...	...	...	...	...
50345	41772	5	118	201	Home	Formal education	Study	14.000000	15.000000	1.000000
50346	41772	5	125	201	Home	Work,study break	Leisure	15.000000	17.000000	2.000000
50347	41772	5	105	201	Home	Preparing food, cooking etc	Home care	17.000000	21.000000	4.000000
50348	41772	5	127	201	Home	Watching tv,video,dvd,music	Leisure	22.000000	23.500000	1.500000
50349	41772	5	101	201	Home	Sleeping	Sleep	23.500000	4.000000	4.500000

Data pre-process

EPFL

TRANSP-OR

2016-2020 UK TUS → Cleaning the data

↓

Aggregate consecutive 10-min inervals with the same "primary activity" and "location"

↓

Calculate activity start time, end time, and duration based on aggregated primary activity data

↓

Reclassify 31 activity categories to 8 activity classifications → **Readable schedules** → Categorize individuals into 3 groups based on employment status (Student, Employed, Not working)

↓

For each employment status category (Student, Employed, Not working)

Plot the distribution of "start_time" and "duration" of each activity category

↓

Determine the preferences of each activity category for each employment status group → **Scheduling preferences**

Scheduling model

- Scheduling preferences
- Feasible time windows
- Flexibility profiles
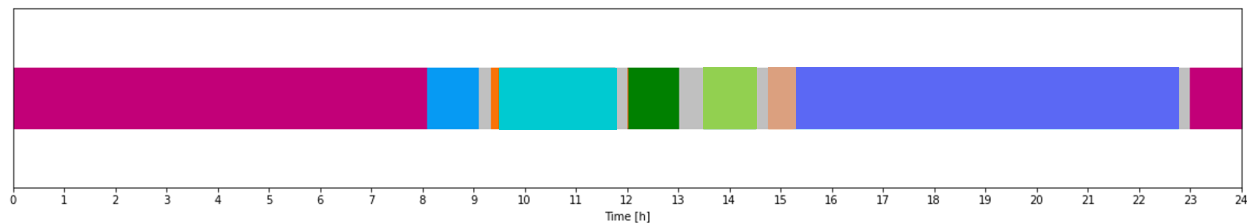- Penalties

→ Scheduling model simulator

Some results:
Student (weekday)

Legend:
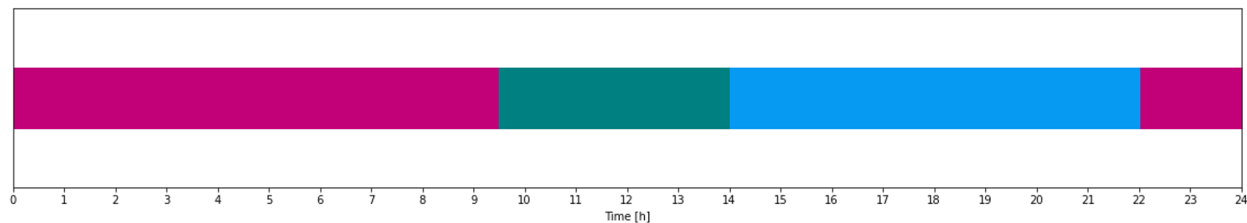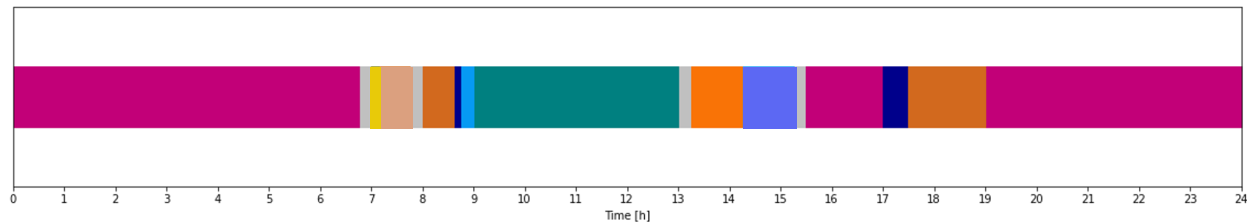
- Sleep
- Work (Home)
- Work (Work)
- Leisure (Home)
- Leisure (Other)
- Study (Home)
- Study (Other)
- Personal care (Home)
- Personal care (Other)
- Shopping (Home)
- Shopping (Other)
- Homecare
- Organisational work (Other)
- Trips

Further model extensions

- One major opportunity to extend the current scheduling approach is to investigate the **household interaction effects** and **interpersonal dependencies.**

- **What are the inter-household interactions?**

Further model extensions

- One major opportunity to extend the current scheduling approach is to investigate the **household interaction effects** and **interpersonal dependencies.**

- **What are the inter-household interactions?**

  - Car availability limitation
  - Resource constraints
  - Sharing household maintenance responsibilities by family members
  - Joint participation of household members in maintenance and leisure activities
  - Sharing common household vehicles
  - Facilitation of activity participation of household members with restricted mobility by undertaking pick-up and drop-off trips
  - Coordination of daily rhythms between partners

Further model extensions

- **How can we capture the inter-household interactions?**

Further model extensions

- **How can we capture the inter-household interactions?**

  1. Considers the activity scheduling at the level of **household** (group decision model); rather than at the level of isolated individuals (individual model)

  $$\Omega = \max \sum_{n} \sum_{i} \omega_{i_n} U_{i_n}$$

  Individual n Activity i

  2. Capture **interactions**
     - Terms in utility (altruism, companionship, efficiency, coordination costs)
     - constraints

  3. Capture **resource constraints**

  $$\sum_{n} \omega(t)_{in} r_m \leq C_m \qquad \forall t \in [0, period], \forall m$$

  Activity participation (0/1) at time t   Resource m

References

- Gershuny, J. and O. Sullivan (2021) United Kingdom Time Use Survey Sequence Pre and During COVID-19 Social Restrictions.

- Pougala, J., T. Hillel and M. Bierlaire (2021) Capturing trade-offs between daily scheduling choices, Technical Report, Ecole Polytechnique Federale de Lausanne (EPFL), Lausanne, Switzerland.

Thank you!