Description of the Instances

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The benchmark instances are based on demographic, spatial, and economic data of Vienna, Austria. First, a set of mode of transport classes K are defined consisting of the following types: *Foot*, *Public transport*, *Bike*, *Battery electric vehicle (BEV)* and subtypes corresponding to specific car models, *Internal combustion engine vehicle (ICEV)* and subtypes corresponding to the size of the vehicle and *Taxi*. For both BEV and ICEV several sub-categories are defined which correspond to car models, e.g., for BEVs we consider Smart ED, Nissan Leaf, and Mitsubishi iMiev. The properties of each $k \in K$ are the following:

Parameter	Domain	Unit	Description
ϵ^k	$\mathbb{R}$	g/km	CO_2 emissions per distance unit
G^k	$\mathbb{R}$	kWh	battery capacity
g^k	$\mathbb{R}$	kW	recharging rate
r^k	$\mathbb{R}$	Wh/km (?)	energy consumption
v^k	$\mathbb{R}$	m/s	average speed
c_d^k	$\mathbb{R}$	1/km	cost in Euro per distance
c_t^k	$\mathbb{R}$	1/min	cost in Euro per time
a^k	$\mathbb{R}$	s	additional time needed for setup (e.g., getting to the car, time needed for parking)

Then, a company is constructed consisting of one or more depots $\Delta \subset L$, where each $\delta \in \Delta$ is represented by its GPS coordinate and L is the set of all possible locations. The company has a set of employees P, and a number of available instances n_k of each transport class $k \in K$. Note that $n_k = \infty$ for *foot*, *public transport*, and *taxi*.

Each employee $p \in P$ has a gender $\theta^p \in \{\mathrm{f}, \mathrm{m}\}$, a hierarchy status $h^p \in \{\mathrm{b}, \mathrm{m}, \mathrm{w}\}$ (boss, middle management, worker), an associated office location $\delta^p \in \Delta$, a home location $l^p \in L$, a work start time $\tau^s \in \mathbb{N}$, and a work end time $\tau^e \in \mathbb{N}$ For all $k \in K$ it is specified if employee p is willing to accept offers using transport mode k, denoted by $\omega^{pk} \in \{0, 1\}$, $\forall k \in K, p \in P$.

Then, for each employee $p \in P$ on each day $t \in T$ of the considered time horizon T an ordered list of events $E^{pt} = (e_0^{pt}, \ldots, e_n^{pt})$ is generated (representing a working day of this employee) consisting of the following attributes:

Parameter	Domain	Unit	Description
α^e	$\mathbb{N}$	min	latest arrival (in number of minutes from the start of the time horizon)
β^e	$\mathbb{N}$	min	earliest departure
s^e	$\mathbb{N}$	min	service duration
l^e	L		location
t^e	$\{\mathrm{w}, \mathrm{m}, \mathrm{p}, \mathrm{h}\}$		activity type: *work*, *meeting*, *private*, *home*

Furthermore, for each pair of locations $l_1, l_2 \in L$ a distance d_{ij}^k, travel time t_{ij}^k, and cost matrix c_{ij}^k is computed for each $k \in K$ based on the route from l_1 to l_2 in the road network.

Value Settings

This section describes how the independent values of the variables described above are set. Some of the variables are chosen randomly following the stated probability distribution. In these cases the actual instance is generated by drawing one sample of each of these distributions.

Transport classes:

Parameter	Variability	Scope	Value
ϵ^k	fixed	all	average values of the respective car category (Joanneum Research 2010, source: ask Bernhard)
G^k	fixed	only BEV	taken from the official car specifications
g^k	fixed	only BEV	taken from the official car specifications
r^k	fixed	only BEV	taken from the official car specifications
v^k	fixed	all	foot: 5, bike: 16, car: 30, public transport: 20 [km/h]
c_d^k	fixed	all	total cost of ownership divided by total km (Joanneum Research 2010)
c_t^k	fixed	all	average gross salary in Austria including additional costs for employer
a^k	fixed	all	foot: 0, bike: 120, car: 600, public transport: 300, taxi: 300

Company:

Parameter	Variability	Value
L	fixed	geometric centers of all 250 registration districts of Vienna
T	fixed	one week
Δ	fixed	two locations chosen randomly following the probability distribution $\mathcal{P}^o$ of L, where $\mathcal{P}^o$ is based on statistical data of office locations in Vienna (see Appendix for the definition of $\mathcal{P}^o$)
$\|P\|$	variable	integer value
ν	variable	real value in the interval [0,1] determining n_k, $\forall k \in K$
n_k	fixed	for bikes, BEVs, and ICEVs: between 0 and $\lfloor \nu \|P\| \rfloor$

Employee:

Parameter	Variability	Value
θ^p	fixed	based on demographic data of female and male employees (f: 46.78%, m: 53.22%)
h^p	fixed	$P(h^p = \text{b}) = 0.01$, $P(h^p = \text{m}) = 0.1$, $P(h^p = \text{w}) = 0.89$
δ^p	fixed	chosen uniformly at random out of Δ
l^p	fixed	chosen randomly following the probability distribution $\mathcal{P}^h$ of L, where $\mathcal{P}^h$ is based on statistical data of residential locations in Vienna (see Appendix for the definition of $\mathcal{P}^h$)
τ^s	fixed	chosen randomly following a probability distribution $\mathcal{P}^{\tau^s}$ between 5 and 11 a.m.
τ^e	fixed	τ^s + amount of daily working hours, which are chosen randomly following a probability distribution $\mathcal{P}^{\tau^e}$ which depends on θ^p and h^p
ω^{pk}	fixed	we defined 7 combinations of accepted mode of transports, e.g., car only, public transport only, mixed. For each combination at most different acceptance scenarios are defined. The combinations are chosen randomly based on a probability distribution $\mathcal{P}^\omega$ considering gender and the probability that p has a driving license which itself is based on statistical data. The acceptance scenario of the chosen category is taken uniformly at random.

Events:

Parameter	Variability	Value
α^e	fixed	private activity: at any time outside working hours. Work meeting: at any time within the working hours.
β^e	fixed	$\alpha^e + s^e$
s^e	fixed	private meetings in the morning 60 minutes, in the evening 120 minutes. Work meetings between 30 and 180 minutes based on probability distribution $\mathcal{P}^{s^e}$.
l^e	fixed	based on $\mathcal{P}^h$ for private activities, on $\mathcal{P}^o$ for work meetings
t^e	fixed	for each day: private activity in the morning with 20% probability, in the evening with 65% probability. The number of work meetings is based on h^p which results in a average amount of time spent in meetings. A meeting is inserted into the daily schedule of the employee until this time is spent or it does not fit in anymore.

Distance, travel time, and cost:

Parameter	Variability	Value
d_{ij}^k	fixed	Aerial distance between i and j multiplied by a constant sloping factor of the respective mode of transport k
t_{ij}^k	fixed	$\frac{d_{ij}^k}{v^k}$
c_{ij}^k	fixed	$c_d^k d_{ij}^k + c_t^k t_{ij}^k + \epsilon^k c_e$, where c_e are the CO_2 costs which are set to 5 Euro per ton.

Generation of the Mobility Offers Based on the data described above we extract mobility demands and offers which form the actual instance of our optimization problem. First, we generate the set of mobility demands D by considering the events $E^p = \bigcup_{t \in T} E^{pt}$ of each employee $p \in P$. Since we assume that the company fleet is located at the depots Δ, each mobility demand $d \in D$ consists of a tour starting and ending at the office location δ^p of the corresponding employee p. Therefore we construct the set of demands $D^p = \{d_0^p, \dots, d_m^p\}$ with $d_i^p = (e_j^p, e_{j+1}^p, \dots, e_q^p) \subseteq E^p$ with $q > j$ for all $j = 0, \dots, n$ with $t^{e_j^p} = t^{e_q^p} = \mathrm{w}$, $\forall i \in 0, \dots, m$ for each employee $p \in P$.

For each $p \in P$ and each $d^p \in D^p$ a set of mobility offers O^{d^p} is created. There is one offer for each transport class $k \in K$ which is accepted by the employee, i.e., for which $\omega^{pk} = 1$, denoted by $k^o \in K$. Each offer $o^{d^p} \in O^{d^p}$ has an *absence period* $[a_{o^{d^p}}, b_{o^{d^p}}]$ with $a_{o^{d^p}}, b_{o^{d^p}} \in \mathbb{R}$ defining its start time $a_{o^{d^p}}$ and end time $b_{o^{d^p}}$. The start time $a_{o^{d^p}}$ is given by the latest arrival $\alpha^{e^p_{j+1}}$ of the first event of the associated demand subtracted by half the setup time $\frac{1}{2}a^{k^{d^{o^p}}}$ and the travel time $t^{k^o}_{l_1,l_2}$ with $l_1 = l^{e^p_j} = \delta^p$ and $l_2 = l^{e^p_{j+1}}$. The end time is given by $b_{o^{d^p}} = \beta^{e^p_q} + t^{k^o}_{l_3,l_4} + \frac{1}{2}a^{k^{d^{o^p}}}$ with $l_3 = l^{e^p_q}$ and $l_4 = \delta^p$ resulting in a duration $\pi_{o^{d^p}} = b_{o^{d^p}} - a_{o^{d^p}}$.

Finally, the cost $c_{o^{d^p}}$ of each offer $o^{d^p} \in O^{d^p}$, $\forall d^p \in D^p, p \in P$ is generated based on the cost matrix of the relevant events and the corresponding transport class $k^{o^{d^p}}$. The salary costs which depend on the duration of the offer are, however, only considered for *work events*, i.e., the journeys from work to the meetings and from the meetings back to work. More specifically, the cost of an offer o^{d^p} with $d^p = (e^p_j, e^p_{j+1}, \ldots, e^p_q)$ contains the setup costs C_S and the travel costs C_T is $C^o = C_S + C_T$ with:

$$C_S = a^{k^{o^{d^p}}} c_t^{k^{o^{d^p}}}$$

$$C_T = \sum_{i=j}^{q-1} c^{k^{o^{d^p}}}_{l^{e^p_i} l^{e^p_{i+1}}} - 0.8 t_{l^{e^p_i} l^{e^p_{i+1}}} c_t^{k^{o^{d^p}}} (1 - \Gamma_{e^p_i e^p_{i+1}}), \text{with}$$

$$\Gamma_{e^p_i e^p_{i+1}} = \begin{cases} 1 & \text{if } (t^{e^p_i} = \text{w} \wedge t^{e^p_i} = \text{m}) \vee (t^{e^p_i} = \text{m} \wedge t^{e^p_i} = \text{w}) \\ 0 & \text{else} \end{cases}$$