Hybrid Heterogeneous Electric Fleet Routing Problem with City Center Restrictions

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Motivation

↑ population in the city
↑ need of transportation

→ congestions
→ increase CO_2 emissions

↓ living quality
↓ tourism

http://miovision.com/blog/europes-most-congested-cities/

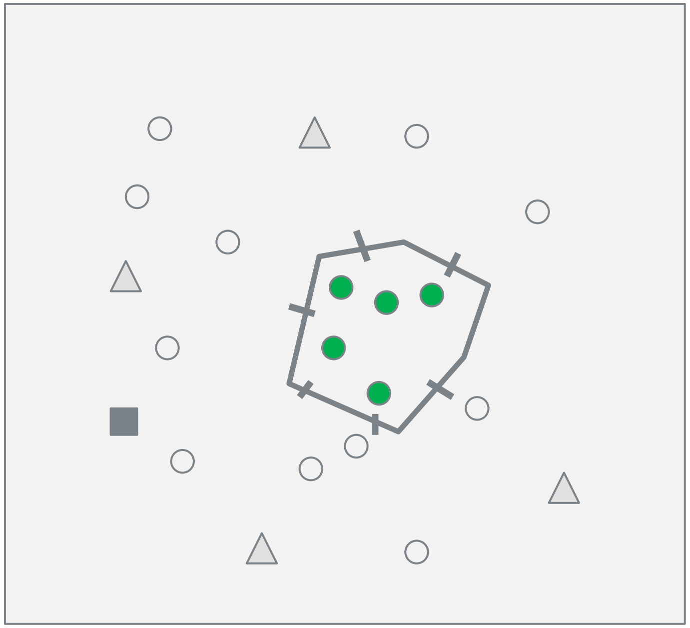
http://www.elephantjournal.com/2012/04/hard-to-breathe-top-10-polluted-u-s-cities/

City Centers

- a City Center (CC) is an Area
- with a finite number of entry points (crossing streets)
- partitions the set of customers into
  - Inside C_1 (green)
  - Outside C_2
- any path between u and v

  $$u \in C_i, v \in C_j, i \neq j$$

  consists of an odd number of entry points
- not necessarily euclidian distances



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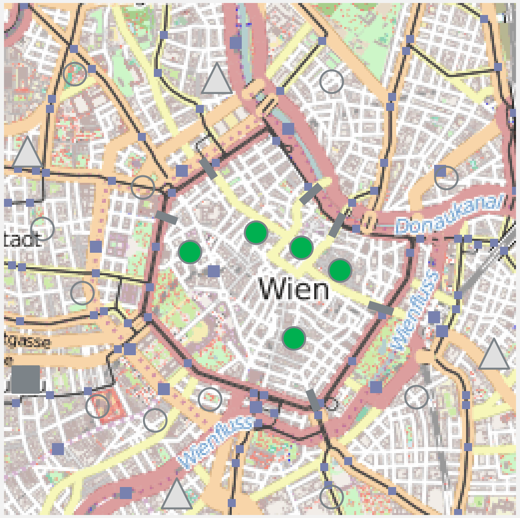
  consists of an odd number of entry points
- not necessarily euclidian distances
- could also be defined on a street map

City Centers Restrictions

- Time restrictions
  - e.g. prohibited from 9-17h
- Engine
  - e.g. no internal combustion engines
- Vehicle type
  - e.g. only small vehicles / bikes
- Penalization
  - one time fee
  - per km cost
  - general prohibition



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(Hybrid) Electric Vehicles

- Eco-friendly(ier) way to travel
- Technological advances
  - extended range
  - more cost-efficient

http://cleantechnica.com/2014/06/10/sales-nissan-e-nv200-electric-van-begin-october/

- Battery Electric Vehicles (BEV)
  - pure electric engine
  - no local CO_2 emissions

http://www.toyota.com/prius-plug-in-hybrid/

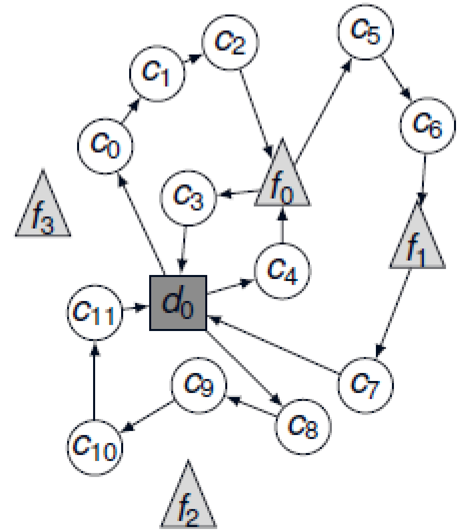
- Plug-in Hybrid Electric Vehicles (PHEV)
  - two engines: internal combustion engine (ICE) and pure electric engine
  - separately rechargeable battery (recharging station)
  - on-the-fly switch between engines

Hybrid Heterogeneous Electric Vehicle Routing Problem with Time Windows and recharging stations

- 3 vehicle classes
  - Internal Combustion Engine Vehicles (ICEV)
  - Battery Electric Vehicles (BEV)
  - Plug-in Hybrid Electric Vehicles (PHEV)

- 2 engine types
  - internal combustion engine
  - pure-electric engine

- Sub-types differing in
  - transport capacity
  - acquisition/utility cost
  - battery capacity
  - energy/fuel consumption rate



Fossil Fuel		Energy
ICEV	PHEV	BEV

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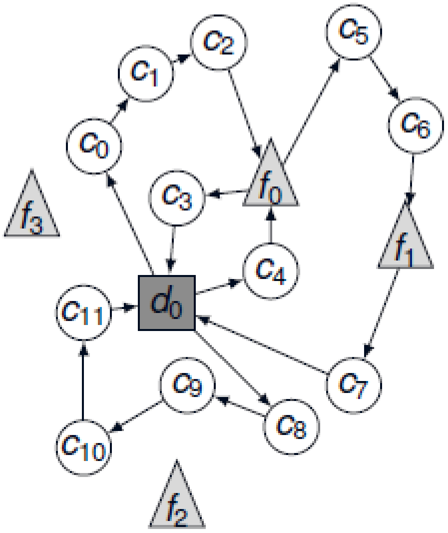
Hybrid Heterogeneous Electric Vehicle Routing Problem with Time Windows and recharging stations

- E-VRPTW (Schneider et al., 2014) with
  - single depot (d)
  - customers (C)
    - demand
    - service time windows
  - recharging stations (F)
    - with partial recharging
  - different cost for using energy or fossil fuel

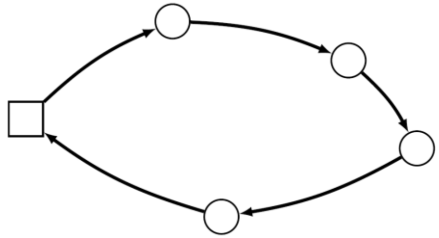


- Assumptions:
  - linear recharging and consumption rate
  - unlimited number of vehicles per type available (fleet size and mix-variant)

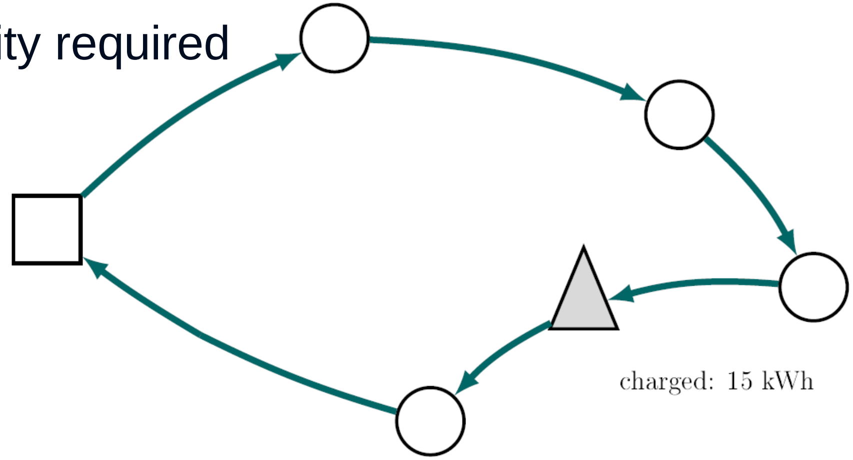
Fossil Fuel		Energy
ICEV	PHEV	BEV

Routing Problems

- Internal Combustion Engine Vehicles => VRPTW
  - well researched topic

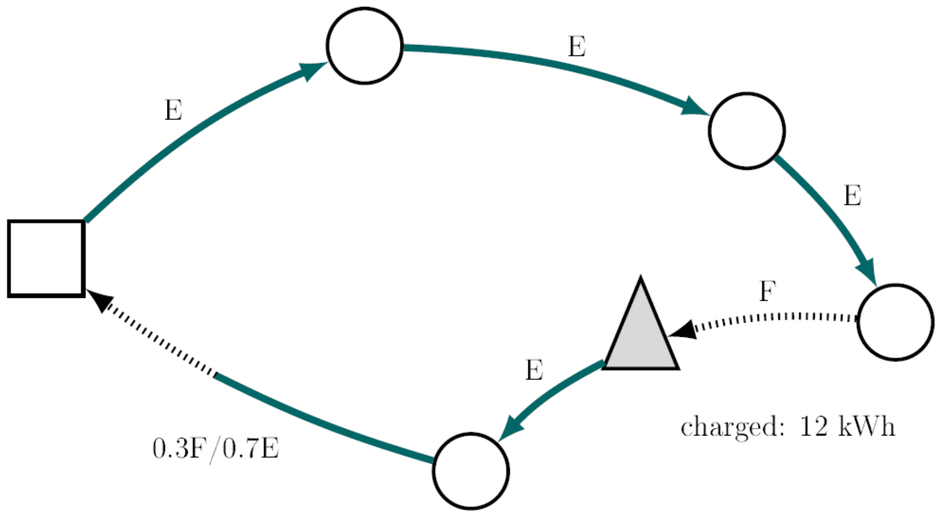


- Battery Electric Vehicles => E-VRPTW(PR)
  - visits to additional nodes (recharging stations) for recharging
  - partial recharging (PR)
    - no recharge to maximum capacity required
    - additional decision on the amount recharged per visit



Routing Problems

- Plug-in Hybrid Electric Vehicles
  - visits to additional nodes (recharging stations) for recharging
  - partial recharging assumed as well
  - decision when to use
    - pure electric engine
    - ICE

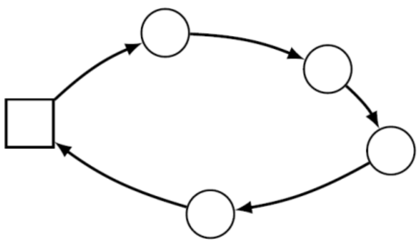


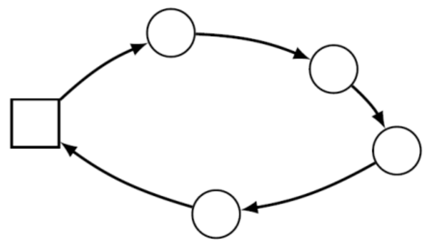
  - Assumption
    - use of energy is always better

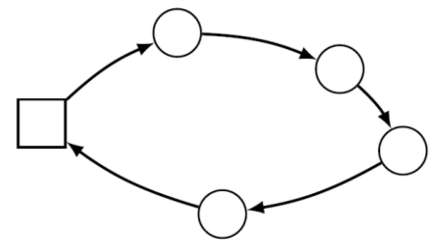
Methodology – Decision Layers

BEV

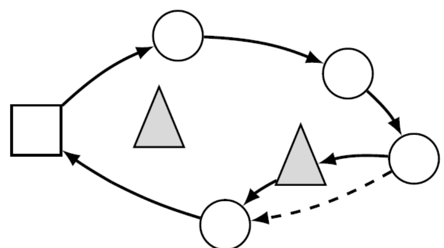
PHEV

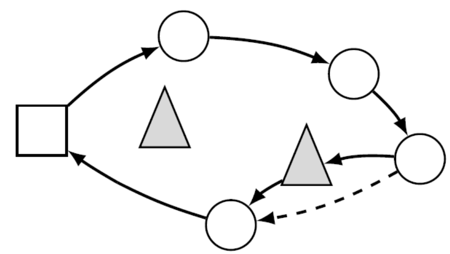






itinerary





RS visits

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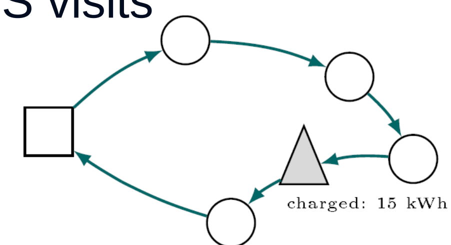
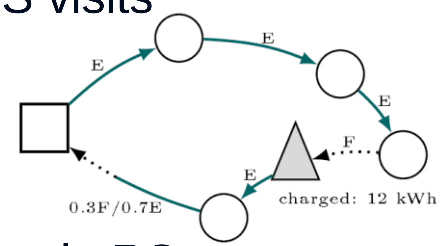


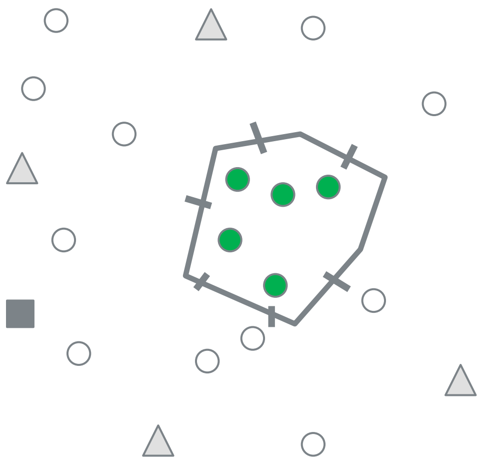


charge in RS

charge in RS

mode selection

Additional Decision: Leg use



- a leg is described by
  - from / to node
  - all intermediate entry points used
  - distance / time / energy needed
- list of possible legs between all non-entry nodes
  - only non-dominating legs stored (preprocessing)
- required to travel between inside and outside nodes
- but also for outside / outside (inside / inside)
  - we can take a shortcut through the city center
  - or drive around the center (i.e., avoiding low speed limits)

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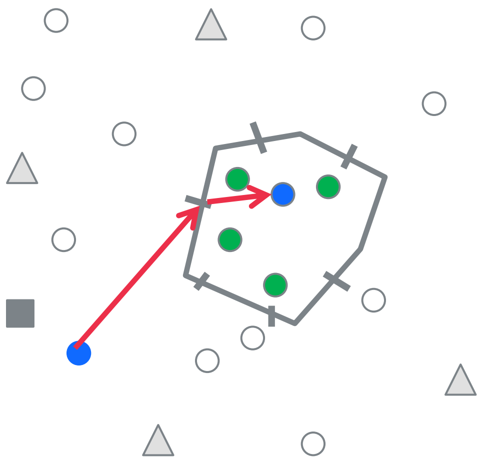

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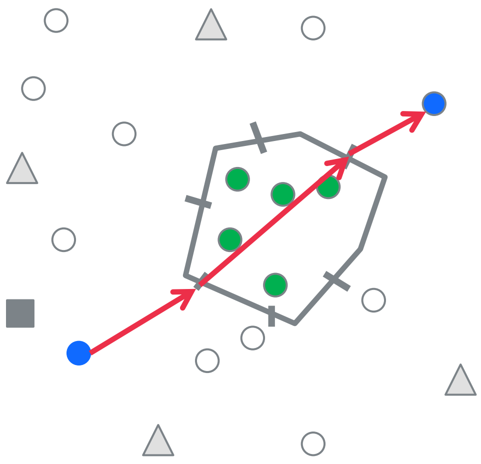

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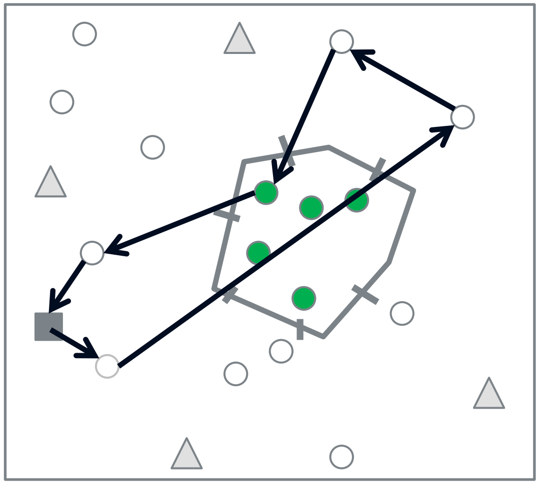
  - additional decision layer using dynamic programming / labelling



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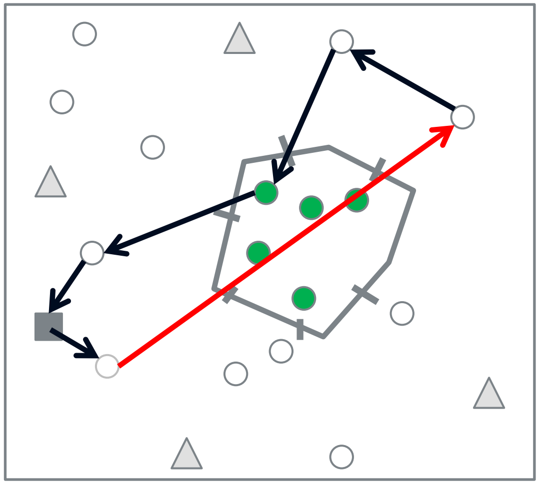

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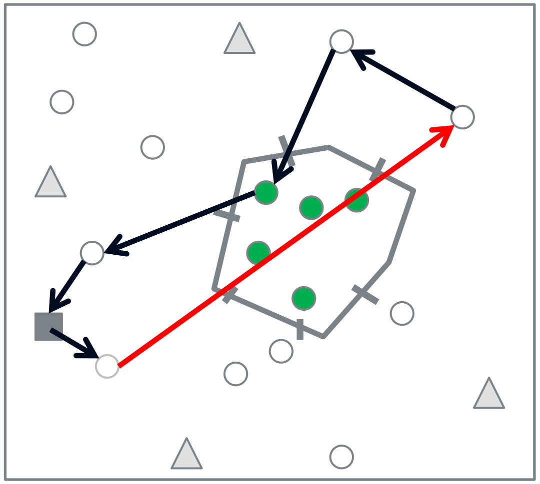

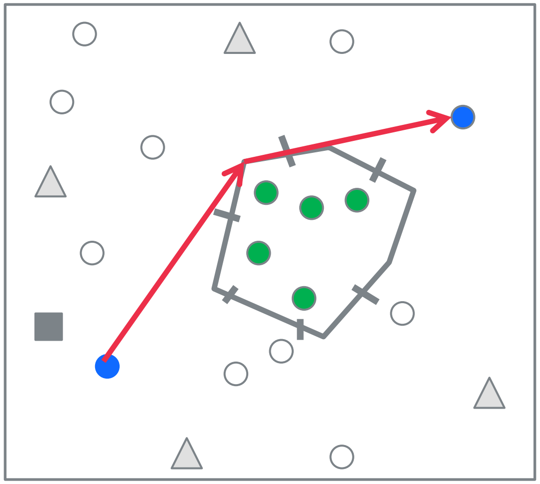

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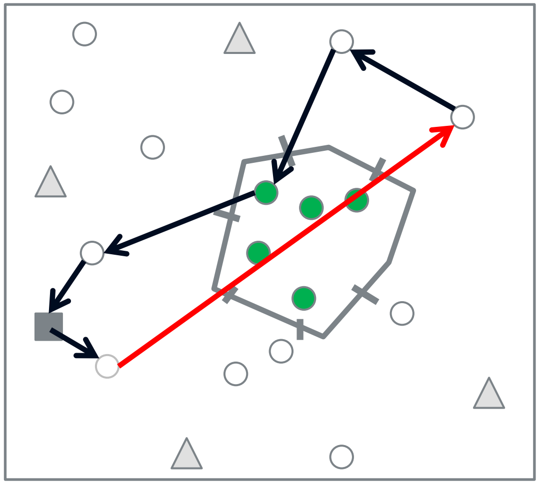

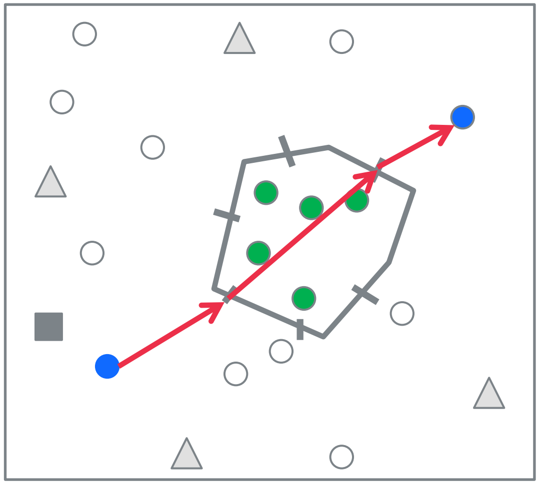

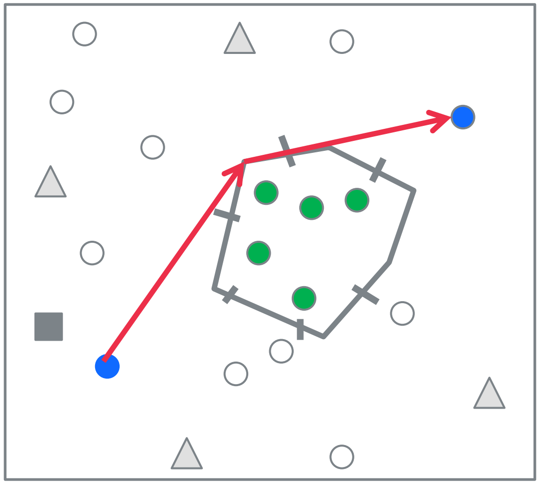

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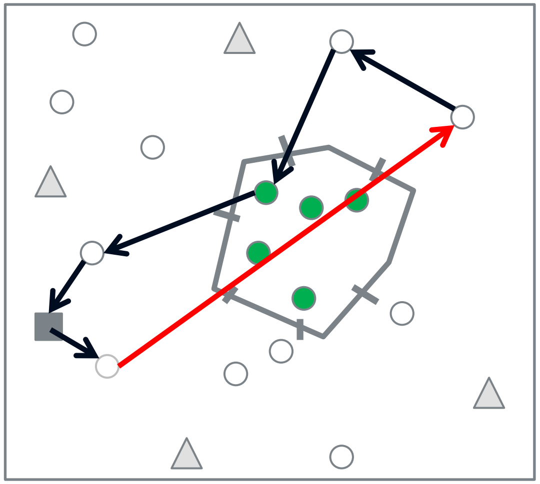
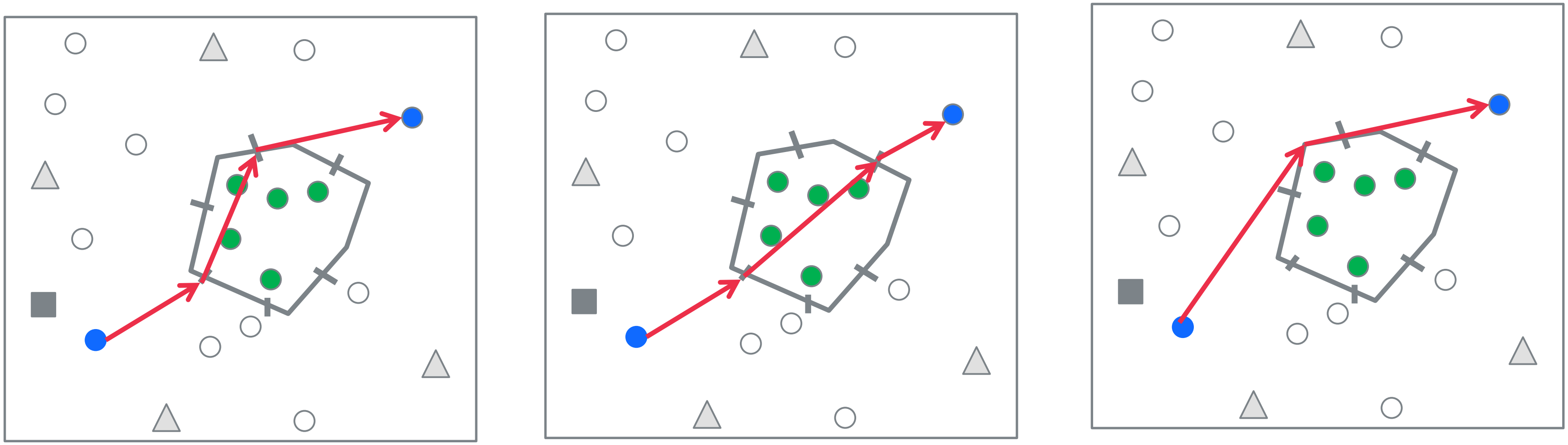
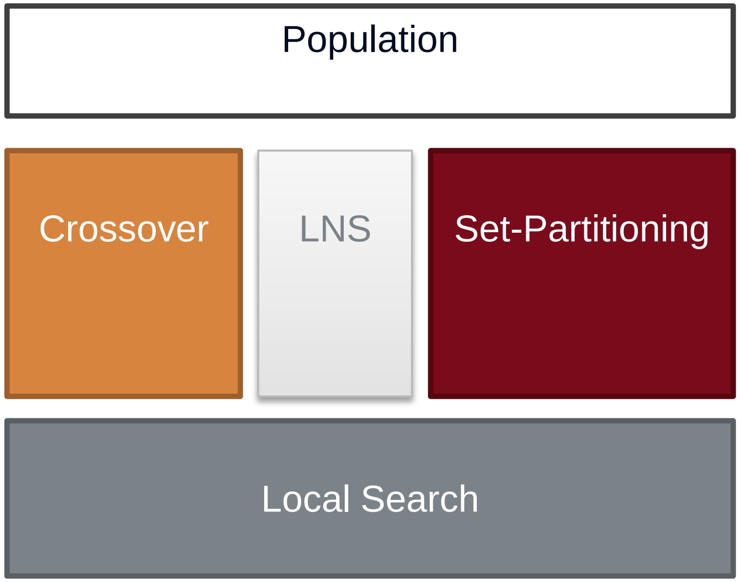




Heuristic Solver

- Population-based Metaheuristic (Hybrid Genetic Algorithm (Vidal et al., 2013))
- Crossover (OX, split)
- Set Partitioning
- Local Search (Education)
  - 2Opt, 2Opt*
  - Relocate (1-2), Swap (0-2)
  - also used as a heuristic repair step (multiply penalties by 10/100)
- Penalization
  - load capacity and time-window relaxation



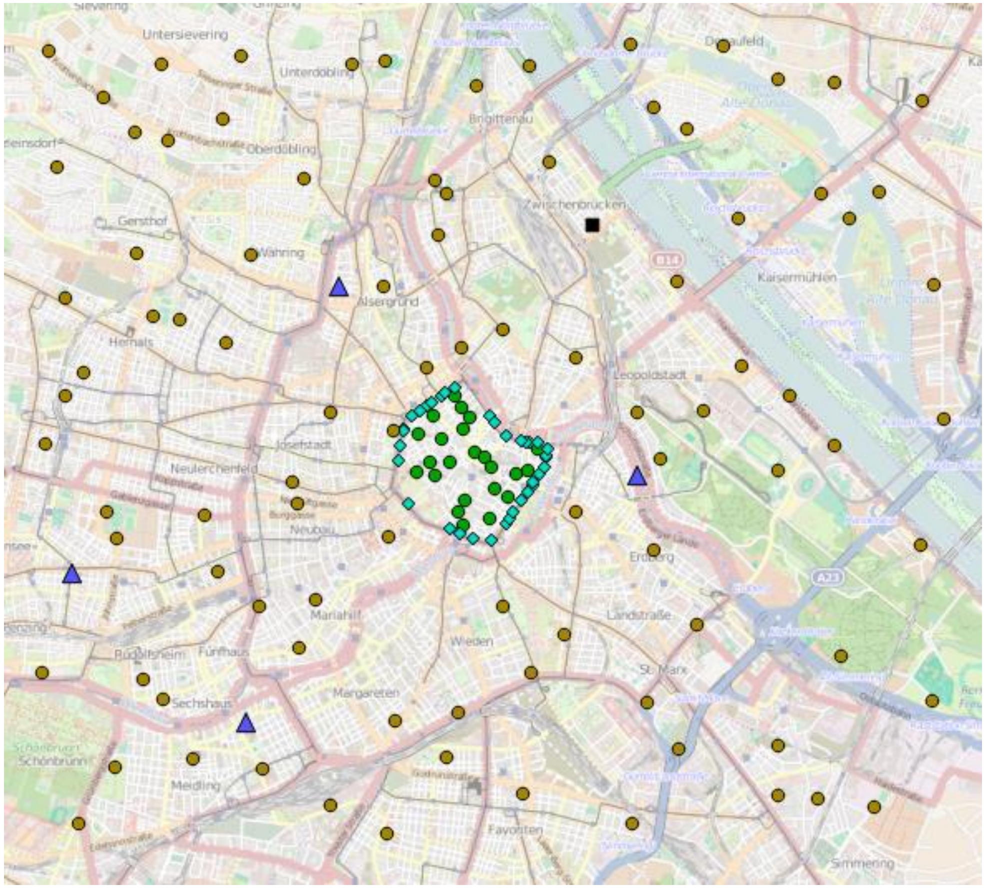
Experiments (preliminary)

- Vienna!

- random node locations
  - 1 depot
  - 5 recharging stations
  - 116 customers
  - 35 entry points

- properties
  - 8h planning horizon
  - random demand
  - time window (1-2h)

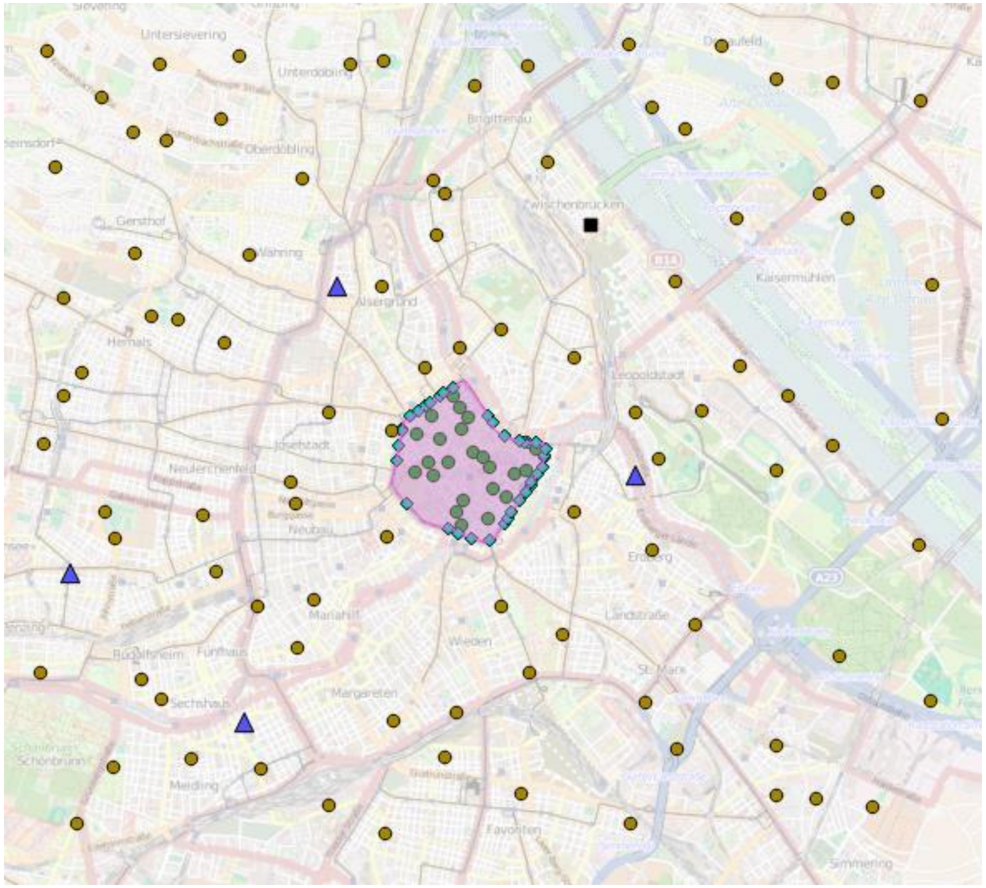
- Configuration based on Fraunhofer study (Plötz et al. 2013)
  - small / medium sized vehicles
  - utility cost also includes driver wage



Experiments (preliminary)

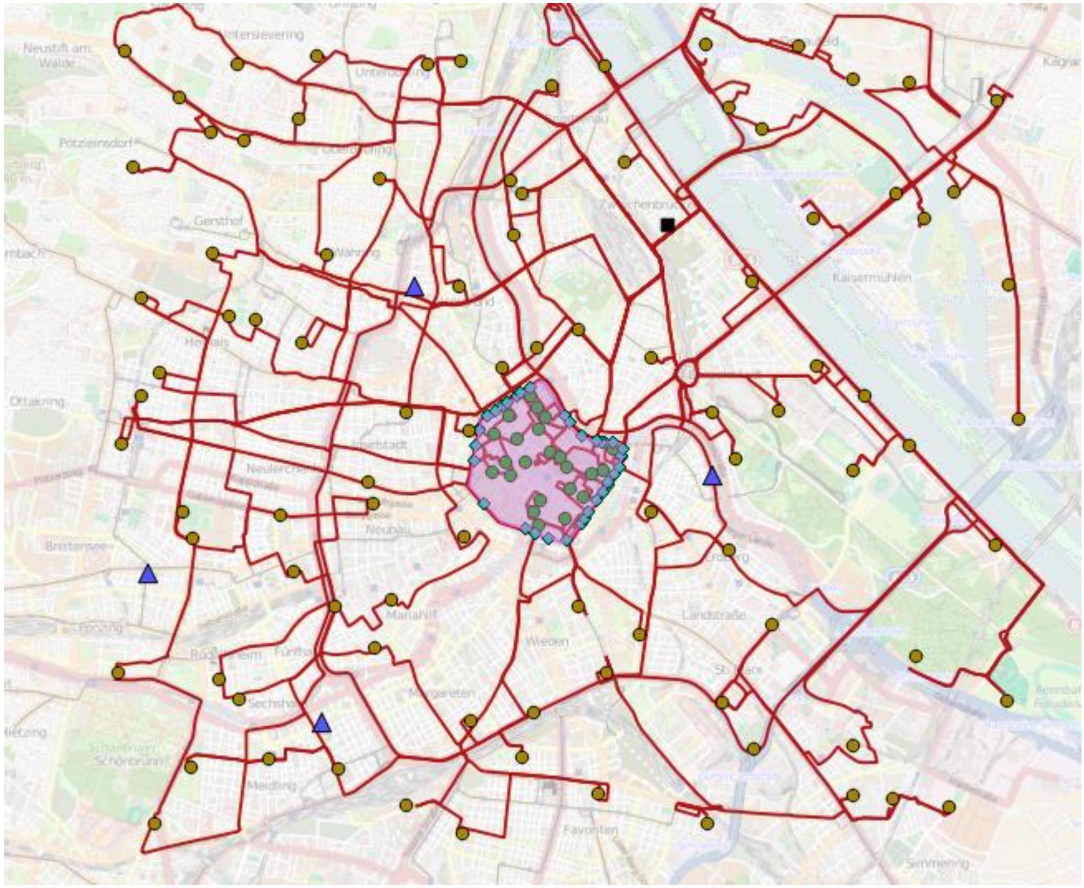
- City center
  - 1st district
  - entry points
    = major access roads

- Restrictions (preliminary tests)
  - without restrictions
  - prohibition of internal combustion engine
    - only BEV and PHEV
    - PHEV have to use energy only



Experiments – without restrictions

10 ICE (medium)



obj: 1825.97
km (total): 395.86
km (inside): 18.78
km (outside): 355.03

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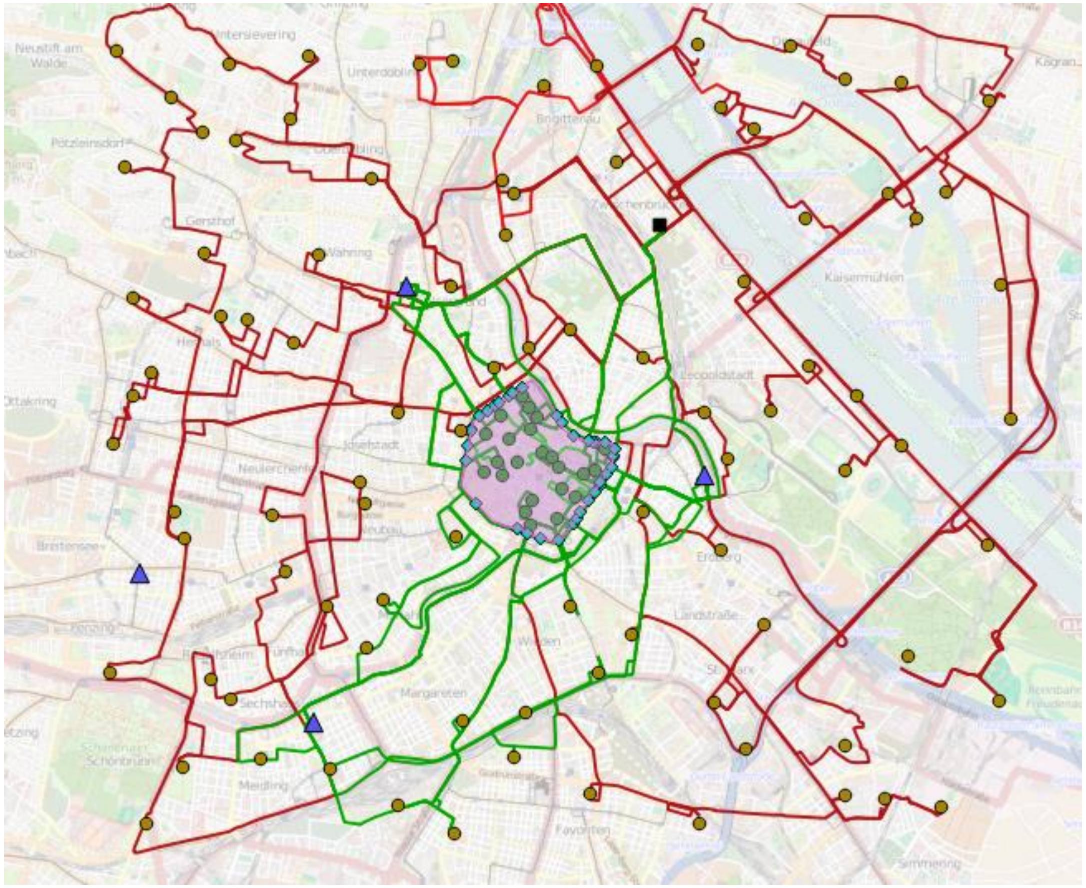
Experiments – with restrictions (no ICE allowed)

1 ICE (small)
7 ICE (medium)
1 BEV (small)
3 BEV (medium)

obj: 1981.50
km (total): 276.65
km (inside): 11.13
km (outside): 265.52



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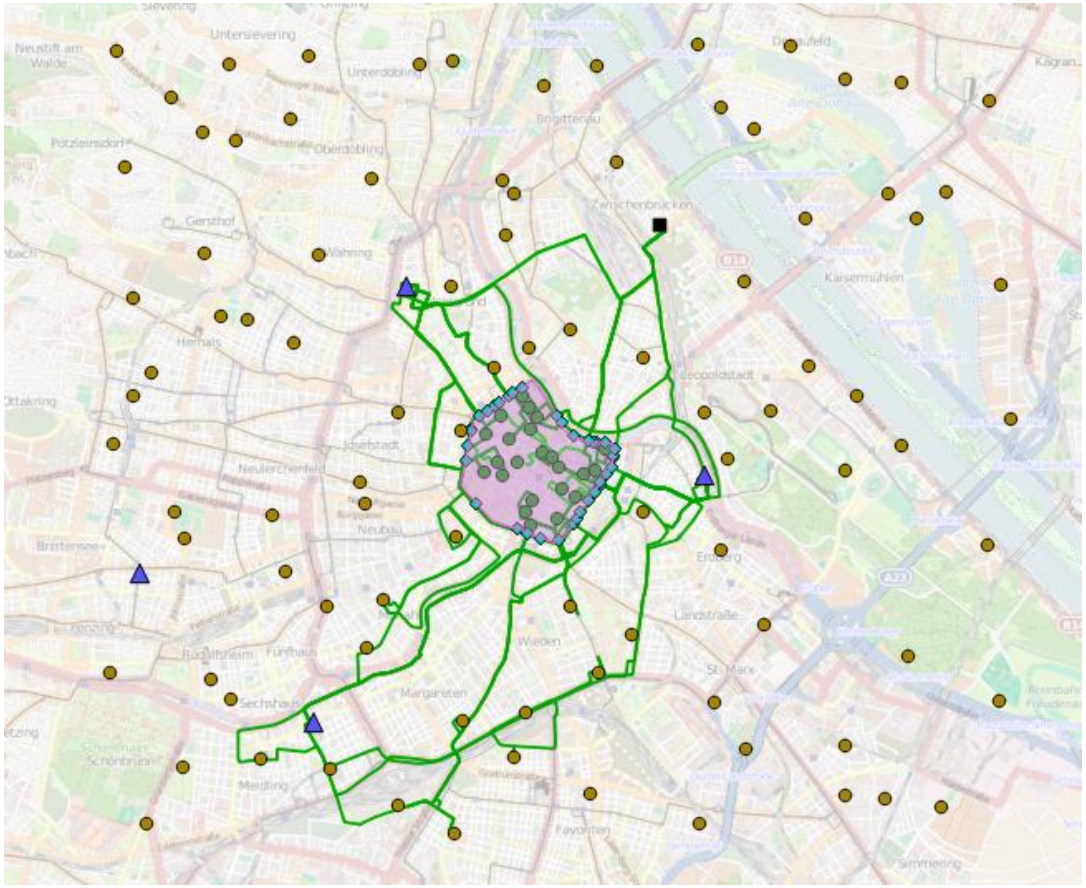

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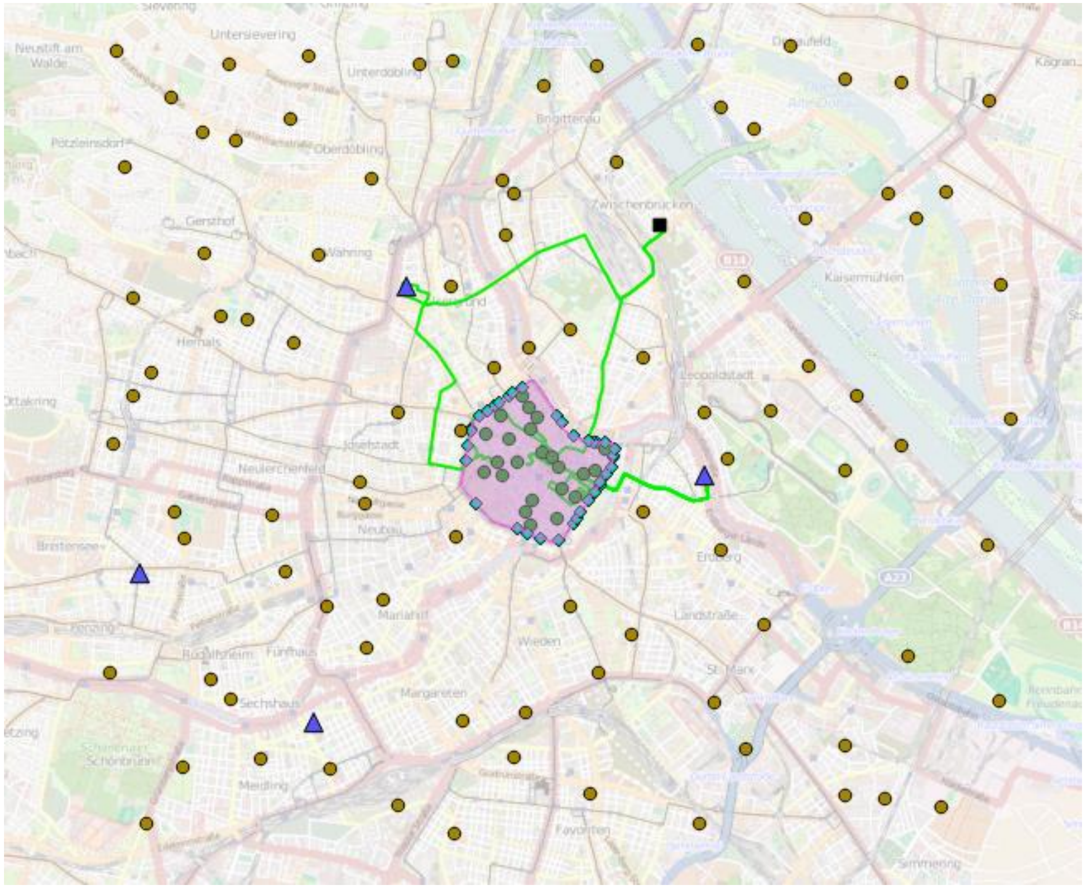

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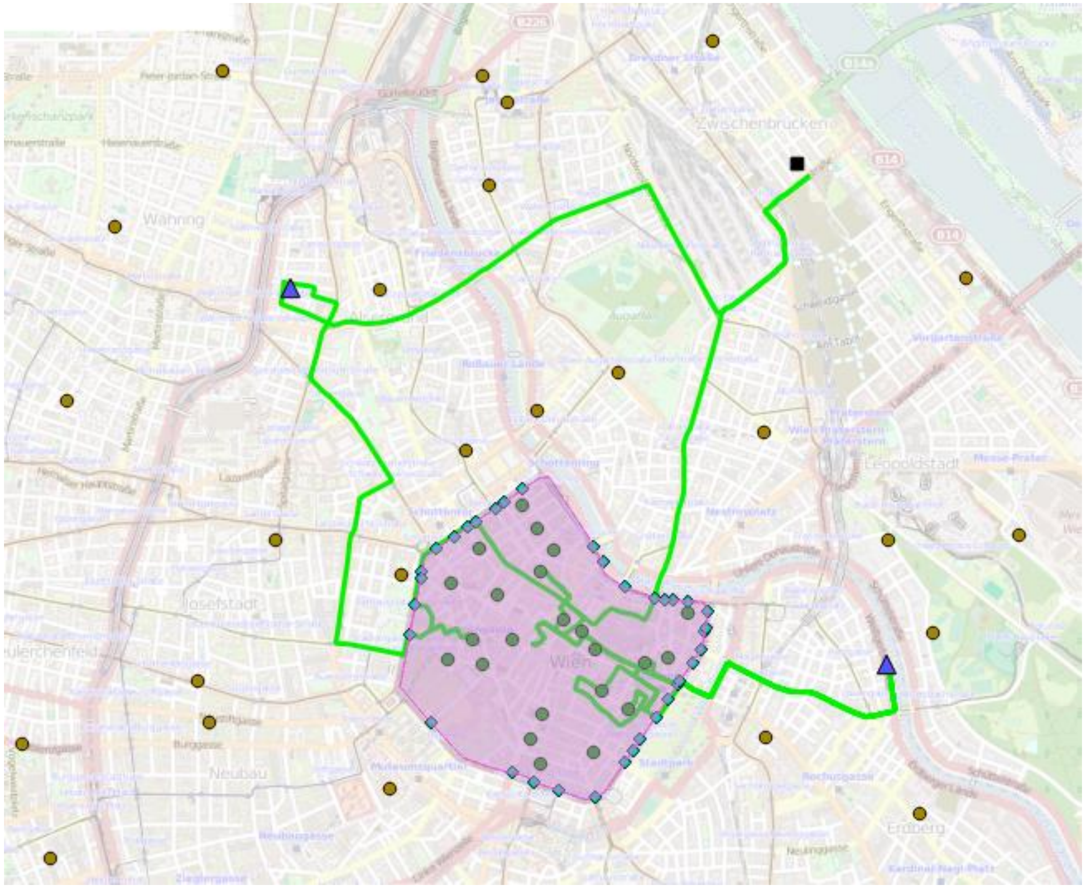


Summary

- Definition of city center restrictions
  - additional constraints for tour planning
  - not just site-dependent restrictions but spatial implications => detours and shortcuts

- Methodology
  - DP/Labelling for for deciding which leg to use
  - fits into the existing approach for the HHEVRPTW

- Results on preliminary experiments
  - utility/acquisition cost major factor
  - PHEVs not cost-efficient enough in the current setup

Future work

- Some open questions
  - how to promote (expensive) PHEVs
  - different objective function (minimizing local CO_2 emissions)
  - urban consumption / emission rates

- Artificial benchmark instances
  - extending classical solomon instances
  - using real world street maps

- Analysis of restrictions types
  - effect on the tour planning
  - different restriction types / policies

Thank you for your attention!

Acknowledgement

This work is partially funded by the Austrian Climate and Energy Fund within the "Electric Mobility Flagship Projects" program under grant 834868 (project VECEPT).

VECEPT
ELECTRIC VEHICLE WITH COST EFFICIENT POWERTRAIN

klima+ energie fonds

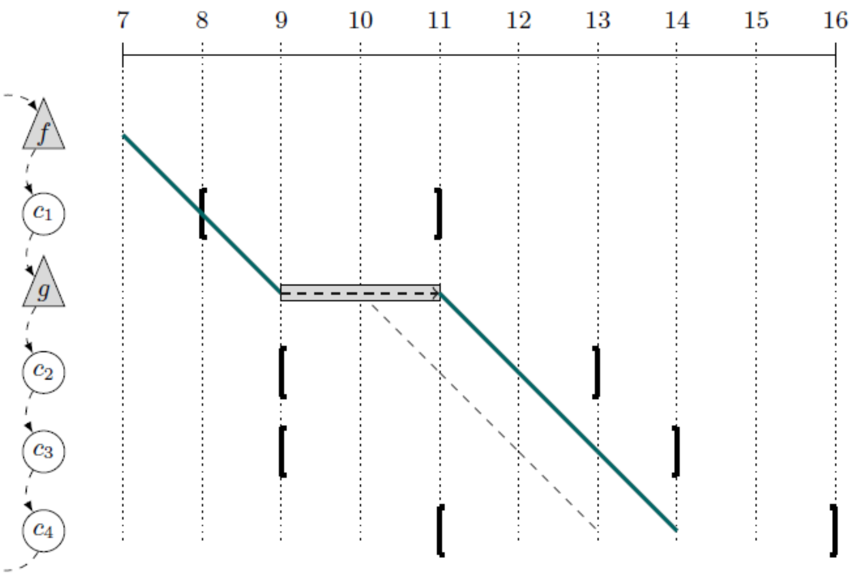
References

- (Schneider et al., 2014) Schneider M, Stenger A, and Goeke D. The electric vehicle routing problem with time windows and recharging stations. Transportation Science, 48(4):500-520.
- (Vidal et al. 2013) Vidal T, Crainic TG, Gendreau M, and Prins C. A hybrid genetic algorithm with adaptive diversity management for a large class of vehicle routing problems with time-windows. Computers & Operations Research, 40(1):475-489.
- (Plötz et al. 2013) *Markthochlaufszenarien für Elektrofahrzeuge.* Karlsruhe : Fraunhofer ISI, 2013.

Additional Slides

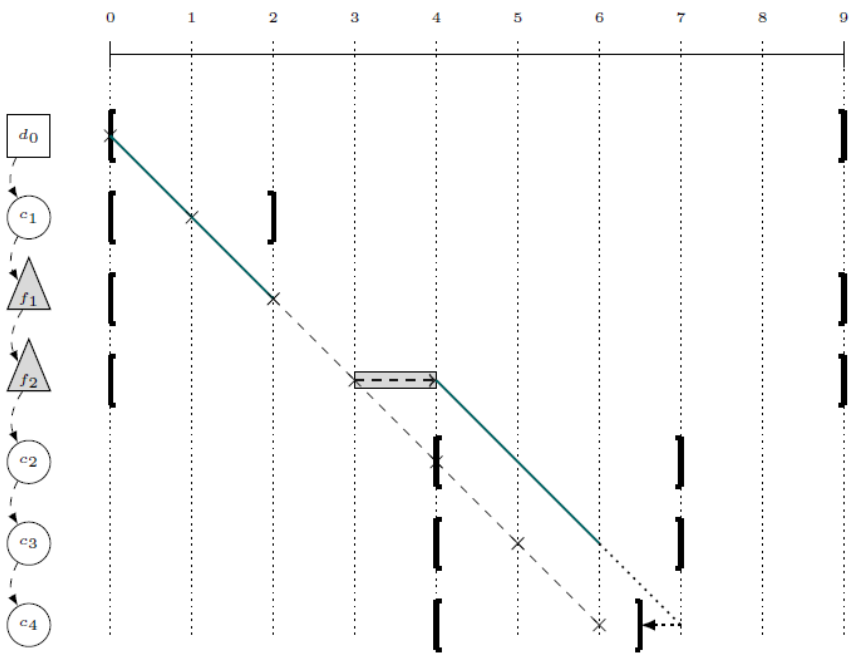
Evaluation for Battery Electric Vehicles

- Assumptions
  - recharging rate is linear (time)
  - energy consumption is also linear (distance)
- Decision
  - quantity to recharge
  - depends on the energy usage + previous recharges
- Greedy policy for the single recharging rate case:
  - charge only if necessary in the last visited recharging station
    → lazy recharging



Evaluation for Plug-in Hybrid Electric Vehicles

- Assumptions
  - recharging rate is linear (time)
  - energy consumption is also linear (distance)
  - no constraints or additional costs for mode switching
- Decision
  - quantity to recharge
  - which engine to use when or
  - how much is energy/fuel is needed
- Greedy policy
  1. energy ← time (lazy recharging)
  2. fuel → time (lazy engine switch)

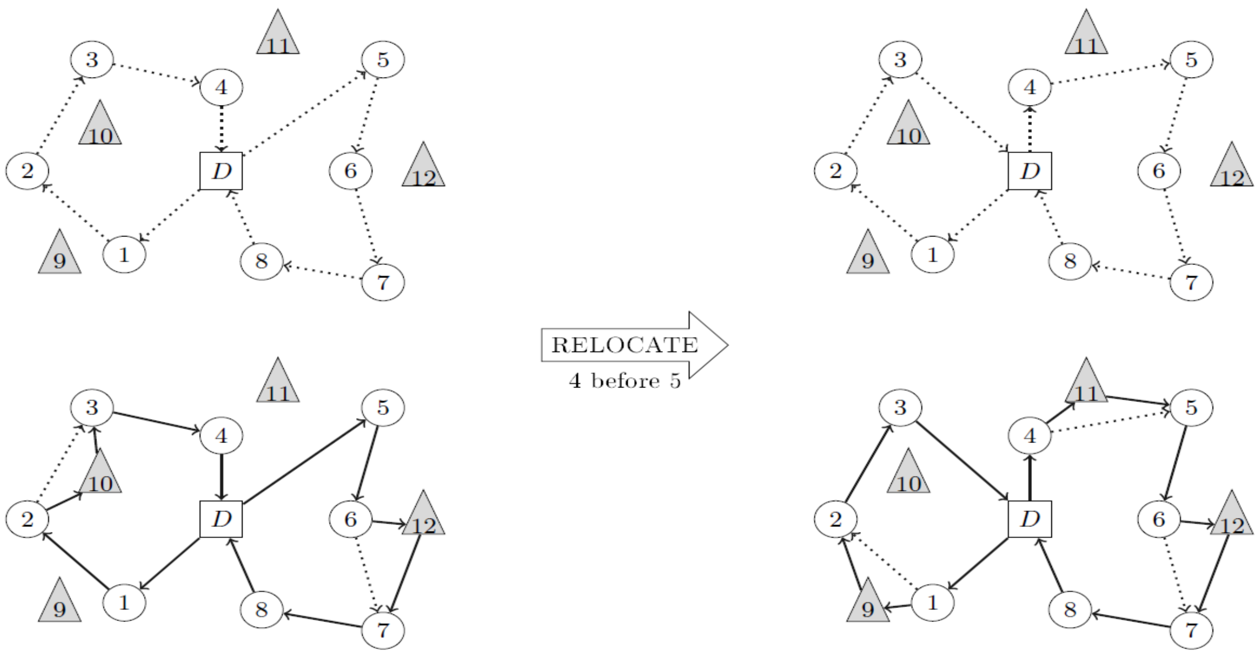


Implicit handling of Recharging Stations

Neighbourhood Search: Relocation Operator

i	$dist_{0,i}$	$dist_{i-1,i}$
1	4	/
2	4	3
3	5	5
4	2	4
5	4	3
6	3	3
7	5	3
8	3	3
$dist_{i,j} = dist_{j,i}$		
other distances $= \infty$		

	$dist_{i,j}$			
$i \backslash j$	9	10	11	12
0	5	4	3	6
1	2	5	/	/
2	3	3	/	/
3	/	3	5	/
4	/	4	2	/
5	/	/	2	3
6	/	/	4	2
7	/	/	/	4
8	5	/	/	5



σ	$dist(\sigma)$
(0, 1, 2, 10, 3, 4, 0)	19
(0, 5, 6, 12, 7, 8, 0)	19
(0, 1, 9, 2, 3, 0)	16
(0, 4, 11, 5, 6, 12, 7, 8, 0)	21

other properties
$tt_{i,j} = dist_{i,j}$
$[e_i, l_i] = [0, \infty]$
$Y = 10$
$r = 1.0, g = 1.0$