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
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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- 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
- 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
City Centers Restrictions

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(Hybrid) Electric Vehicles

- Eco-friendly(ier) way to travel
- Technological advances
  - extended range
  - more cost-efficient
- Battery Electric Vehicles (BEV)
  - pure electric engine
  - no local CO₂ emissions
- 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

http://cleantechnica.com/2014/06/10/sales-nissan-e-nv200-electric-van-begin-october/
http://www.toyota.com/prius-plug-in-hybrid/
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

<table>
<thead>
<tr>
<th>Fossil Fuel</th>
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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)

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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**
  - RS visits
  - charge in RS: 15 kWh

- **PHEV**
  - RS visits
  - charge in RS: 12 kWh
  - 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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  - additional decision layer using dynamic programming / labelling
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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
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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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 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).
References


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 $\leftarrow$ time (lazy recharging)
  2. fuel $\rightarrow$ time (lazy engine switch)
Implicit handling of Recharging Stations

Neighbourhood Search: Relocation Operator

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other distances = \(\infty\)

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<tr>
<td>((0, 4, 11, 5, 6, 12, 7, 8, 0))</td>
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other properties

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\[ [c_i, l_i] = [0, \infty] \]
\[ Y = 10 \]
\[ r = 1.0, g = 1.0 \]