The Electric Vehicle Routing Problem with Time Windows: trends and insights for future research

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Outline

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The SMILE project focuses on the development of innovative strategies, plans and measures on energy efficient mobility solutions and their implementation in smart Mediterranean cities utilizing all available technologies and building upon previous experiences as well as on-going initiatives.
SMILE project

- SMILE is well aligned with the general objective of promoting innovative energy efficient solutions for smart MED cities as it defines, plans, tests, shares and promotes public policies, strategies and measures for intelligent urban freight transport solutions, improving public and private actors’ knowledge while imposing a direct energy saving impact to the cities.

- Innovative solutions are developed to rationalize and improve the efficiency of transport and promote innovative renewable energy use reducing energy consumption and associated GHG emissions.
Related Initiatives

- **Holistic Energy Chain**
  Research and implementation process of production and distribution of “clean” raw materials and energy, through the implementation of selected pilot plans and their uses in a realistic environment.

- **Use of efficient and clean engines** - electric cars, vans, motorcycles and bicycles. Interfacing with advanced/realistic management and routing algorithms.

- **Electric mobility** in urban freight distribution (pilot activities)
EVRPTW

- Electric Vehicle Routing Problem with Time Windows (EVRPTW)
- Derived from the well-known VRP (NP-hard)
- Homogeneous fleet of depot-returning electric capacitated vehicles
- A set of charge stations
- A set of geographically scattered customers
- Predefined time windows
Problem Description

EVRPTW

- **Hierarchical Objective:**
  1. Minimize the number of vehicles required to service all customers (primary)
  2. Minimize the total distance traveled (secondary)

- **Constraints:**
  - Each customer must be serviced within a hard time window
  - Each customer must be visited only once by exactly one vehicle
  - The load of a vehicle must not exceed a maximum capacity limit at any point along the route.
  - There should be enough electric energy to return to the depot.
Problem Description

EVRPTW

Mathematical model:

\[
\min \sum_{k \in K} \sum_{(i,j) \in A'} d_{ij}x_{ijk} \tag{1}
\]

Subject to:

\[
\sum_{k \in K} \sum_{j \in V'} x_{ijk} = 1 \quad \forall i \in C, \forall k \in K \tag{2}
\]

\[
\sum_{j \in V'} x_{ijk} - \sum_{j \in V'} x_{jik} = 0 \quad \forall i \in V', \forall k \in K \tag{3}
\]

\[
\sum_{k \in K} \sum_{j \in V'} x_{ijk} \leq 1 \quad \forall i \in V' \setminus C, \forall k \in K \tag{4}
\]

\[
x_{i,j,k}(q_{ik} + p_i + t_{ij} - q_{jk}) \leq 0 \quad \forall k \in K, (i, j) \in A' \tag{5}
\]

\[
e_i(\sum_{j \in V'} x_{ijk}) \leq q_{ik} \leq l_i(\sum_{j \in V'} x_{ijk}) \quad \forall k \in K, \forall i \in C \tag{6}
\]

\[
E \leq q_{ik} \leq L \quad \forall k \in K, \forall i \in \{d_o\} \tag{7}
\]

\[
y_{j} \leq y_{i} - \tau d_{ij}x_{ijk} + Q(1 - x_{ijk}) \quad \forall i \in V', j \in C, \forall k \in K, i \neq j \tag{8}
\]

\[
y_{i} \geq \min\{\tau d_{io}, \tau(d_{ij} + d_{jo})\} \quad \forall i \in C, \forall j \in S \cup S' \tag{9}
\]

\[
y_{i} = Q, \quad \forall i \in d_o \cup D \cup S \cup S' \tag{10}
\]

\[
\sum_{j \in C} \sum_{i \in V'} x_{ijk} \leq M, \quad \forall k \in K \tag{11}
\]

\[
x_{ijk} \in \{0, 1\}, \quad \forall i, j \in A', \forall k \in K \tag{12}
\]

\[
y_{i} \geq 0, \quad \forall i \in A' \tag{13}
\]

\[
q_{ik} \geq 0, \quad \forall i, j \in A', \forall k \in K \tag{14}
\]
EVRPTW

Mathematical model:
Based on Cordeau et al. (2001), constraint (5) can be linearized as:

\[ q_{ik} + p_i + t_{ij} - q_{jk} \leq (1 - x_{ijk})B_{ij}, \quad \forall i, j \in A', \forall k \in K \]  \hspace{1cm} (15)

where \( B_{ij} \) represents large constraints that could be replaced by:

\[ \max \{ l_i + p_i + t_{ij} - e_j, 0 \} \quad \forall i, j \in A', \forall k \in K \]
EVRPTW

Problem Description

- **Energy consumption:**
  the **operating mode** of the vehicle and the **usage of air condition/heater** constitute crucial factors

- Operating mode (Davis and Figliozzi, 2013):

\[
E_c = \frac{\rho \cdot ul \cdot fv \cdot v^3}{2} + f \cdot v \cdot w_e \cdot v + g \cdot w_e \cdot v
\]

where, 
- \( v \) (km/h) is the average speed
- \( w_e \) (kg) is the weight
- \( \rho \) represents the air density (km/m³)
- \( ul \) is the coefficient of drag
- \( g \) is the average road gradient (%)
- \( fv \) is the frontal area of the vehicle (m²)
Problem Description

EVRPTW

- **Energy consumption:**
  - Usage of air condition/heater (Koupal, 2001):
    
    \[ df = z + a \cdot hi + b \cdot hi^2 \]
    
    \[ E_c = AF \cdot df \]

    Constants:
    
    \[ z = -3.631541 \]
    
    \[ a = 0.072465 \]
    
    \[ b = -0.000276 \]
    
    (Koupal, 2001)

    **AF:**
    
    (i) for idle (0 km/h) is 36.5%
    
    (ii) for acceleration (0-6 km/h) is 25.4%
    
    (i) for cruise (6-80 km/h) is 18.7% - 12.7%
    
    (USEPA, 2010)
EVRPTW

- **Artmeier et al. (2010):**
  study the most economical plan of routing in terms of energy consumption

- **Conrad and Figliozzi (2011):**
  present a Rechargeable VRPTW where vehicles can be recharged at customer locations during the service process and the first objective is to minimize the total number of vehicles and then, the total routing cost including travelled distance, service time and recharging time

- **Erdoğan and Miller-Hooks (2012):**
  describe a generic Green Vehicle Routing Problem (GVRP) with the aim to minimize the total distance travelled by the vehicles
Schneider et al. (2014): study a vehicle routing problem with intermediate stops which considers necessary visits at intermediate locations with the objective to minimize the sum of the total travel cost and the fixed vehicle cost.

Baouche at al. (2013): present an alternative study for the EVRP and efficient tools are developed to minimize the energy consumption based on dynamic information in an effort to promote the use of electric vehicles in practice.
Davis and Figliozzi (2013): develop a model that integrates routing constraints, speed profiles, energy consumption and vehicle ownership costs to study the competitiveness of three commercial vehicles (one conventional and two different electric).

Barco et al. (2012): propose a scheme that coordinates the routing, charge scheduling and operating costs taking into account the battery consumption as well as the recharging cost and present a case study about carrying passengers from an airport to a hotel using electric vehicles.
Observations (1/2)

EVRPTW

- **Comparisons are not feasible**
  - Different objective functions and constraints

- **Recommendations for future research**
  - Integrated study of the problem
  - Systematic analysis of real-world environment
  - Capture industry perspectives
  - Exploit scientific background
  - Dynamic information (dynamic nature of real-life problems)
  - Realistic constraints
EVRPTW

Observations (2/2)

- Industry information is not available
  - Benchmark data sets used for evaluation derived from classical VRP

- Recommendations for future research
  - Input of practitioners
  - Empirical studies
  - Customers own charging infrastructure offering fast charges
  - Combine pickups and deliveries (increase synergies)
  - Heterogeneous fleet of vehicles
  - Consider costs of recharge and battery consumption
Current trends

EVRPTW

- Use of approximate methods
  - Clarke and Wright heuristic
  - Density-based clustering algorithm
  - Adaptive Variable Neighborhood Search

- Recommendations for future research
  - More sophisticated solution procedures
    Approximation algorithms, memory structures, operators and efficient search mechanisms

Multiple criteria for the evaluation
accuracy, speed, flexibility and simplicity (Cordeau et al. 2005)
Conclusions

- Essential factors that affect the EVRP(TW) are: vehicle utilization, distance travelled, routes, battery life, costs of recharge and battery consumption.

- Commercialization of electric vehicles and their use in urban freight distribution have increased, as a result of the increasing concerns for energy efficiency and reduction of greenhouse gas emissions (GHG).
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http://smile-urbanlogistics.eu/
THANK YOU!

Questions?