Integrated Optimal pricing, sizing and location of electric vehicle charging stations

Clémence Alasseur [3] Miguel F. Anjos [2] **Ikram Bouras** [1]
Luce Brotcorne [1] Alemseged G. Weldeyesus [2] Riadh Zorgati [3]

INRIA Lille - Nord Europe, France[1]
University of Edinburgh, UK[2]
EDF R&D, France[3]

PGMO days 2020 - December 1, 2020

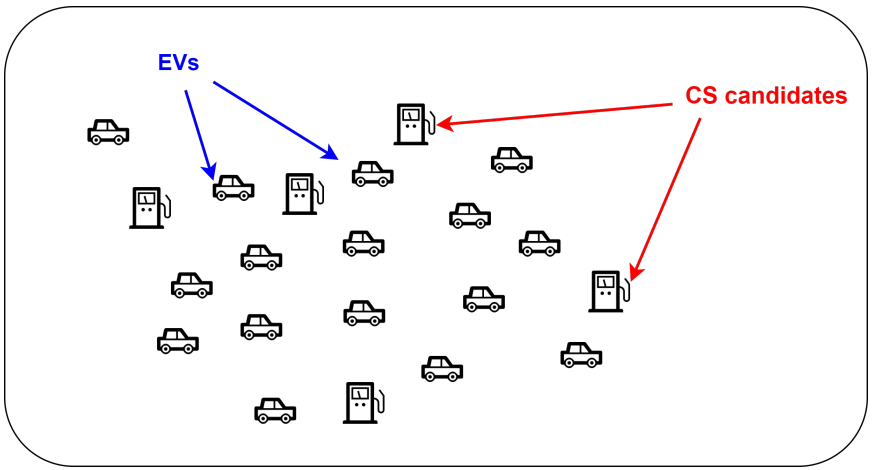
Problem description

Goal:

Determine the optimal pricing, sizing and locations of EVCS in order to maximize the revenue and smooth demand over time.

Context:

- Strategic planning.
- Each EV user has a preference list (Limited size) of charging stations based on: Expected price **and\or** Distance



- Hierarchical decision making process.
- Energy prices are associated to time slots.
- Threshold price and distance for each users.
- Limited budget.

Bi-level optimization model

	Leader: EV charging stations manager	Follower: EV users
Objectif	Maximize the profit + Smooth the demand over time	Each user selects the best CS available in the preference list
Decisions	▶ Select a set of CS to be activated ▶ The number of chrging spots in a CS ▶ Prices associated to time slots	▶ Chooses the CS and the time slot to chrge

Solution methods and numerical results

- **Solution methods:**
  - Single level reformulation of the bilevel model:
    Using KKT optimality conditions $\Longrightarrow$ Solve with ILP solver
  - Cutting plane algorithm:
    Cut infeasible solutions iteratively with valid inequalities.

- **Preliminary numerical results on randomly generated instances:**

Example: 10 users, 5 stations, 3 time slots

Solution when the preference list is defined based on minimum distance

User = 1
[2, 5, 4]
[1, 1, 3]
[5, 5, 5]

User = 6
[4, 5, 2]
[1, 3, 2]
[4, 5, 4]

User = 2
[2, 5, 2]
[3, 1, 1]
[4, 3, 3]

User = 7
[4, 4, 4]
[3, 1, 2]
[5, 5, 3]

User = 3
[4, 3, 1]
[3, 2, 1]
[5, 5, 4]

User = 8
[3, 2, 1]
[2, 3, 1]
[5, 3, 4]

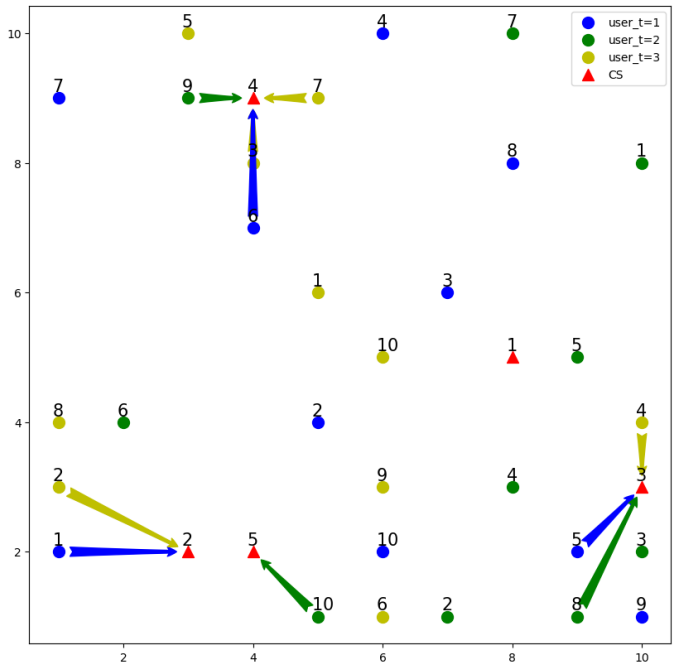
User = 4
[3, 3, 1]
[3, 2, 2]
[4, 4, 4]

User = 9
[4, 3, 5]
[2, 1, 3]
[3, 4, 3]

User = 5
[1, 4, 3]
[2, 3, 1]
[7, 3, 7]

User = 10
[5, 5, 1]
[2, 1, 3]
[7, 3, 7]

Initial Preference list



Revenue
35

User obj value
12

Sizes
y_2=1
y_3=1
y_4=1
y_5=1

Prices
p_2_1 = 5
p_2_3 = 4
p_3_1 = 7
p_3_2 = 5
p_3_3 = 4
p_4_1 = 4
p_4_2 = 3
p_4_3 = 5
p_5_2 = 7

User = 1
[2, 5, 4]
[1, 1, 3]
[5, 5, 5]
x_1_2_1
p_2_1=5

User = 6
[4, 5, 2]
[1, 3, 2]
[4, 5, 4]
x_6_4_1
p_4_1=4

User = 2
[2, 5, 0]
[3, 1, 0]
[4, 3, 0]
x_2_2_3
p_2_3=4

User = 7
[4, 4, 4]
[3, 1, 2]
[5, 5, 3]
x_7_4_3
p_4_3=5

User = 3
[4, 3, 0]
[3, 2, 0]
[5, 5, 0]
x_3_4_3
p_4_3=5

User = 8
[3, 0, 0]
[2, 0, 0]
[5, 0, 0]
x_8_3_2
p_3_2=5

User = 4
[3, 0, 0]
[3, 0, 0]
[4, 0, 0]
x_4_3_3
p_3_3=4

User = 9
[4, 0, 5]
[2, 0, 3]
[3, 0, 3]
x_9_4_2
p_4_2=3

User = 5
[0, 0, 3]
[0, 0, 1]
[0, 0, 7]
x_5_3_1
p_3_1=7

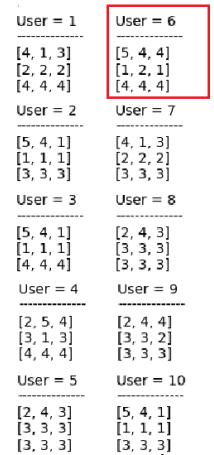
User = 10
[5, 5, 0]
[2, 1, 0]
[7, 3, 0]
x_10_5_2
p_5_2=7

Updated Preference list

All users got their first choice except user 5, because its first choice CS-1 was not acitvated and the price of its second choice was p_4_3 = 7 higher than its price threshold 3.

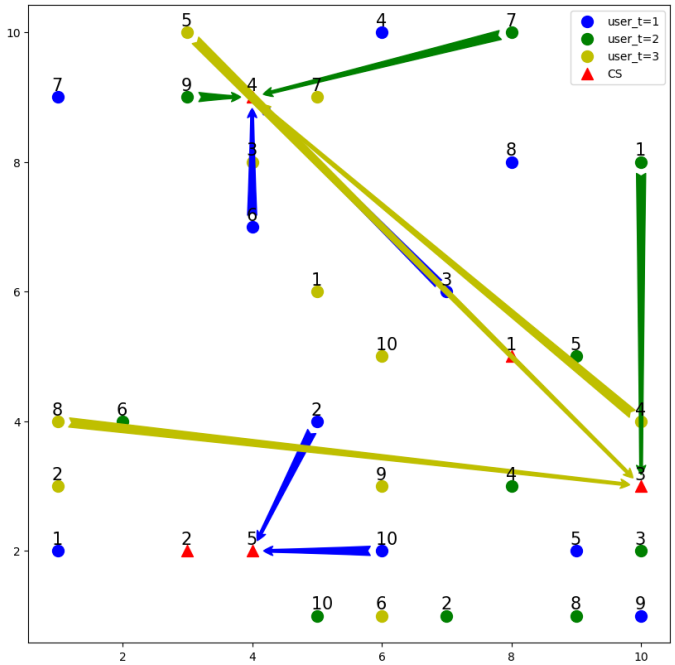
Example: 10 users, 5 stations, 3 time slots

Solution when the preference list is defined based on minimum cost



Initial Preference list

same value

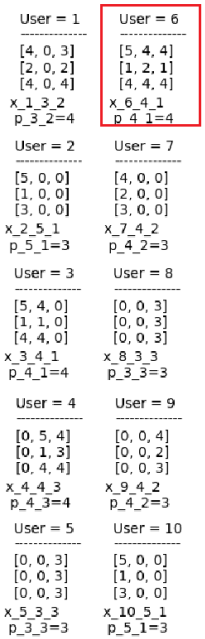


Revenue
21

User obj value
23

Sizes
y_3=1
y_4=1
y_5=1

Prices
p_3_2 = 4
p_3_3 = 3
p_4_1 = 4
p_4_2 = 3
p_4_3 = 4
p_5_1 = 3



Updated Preference list

* Notice the longer arrows (distance).
* User 6 got its third choice, because its first choice CS-5 and third choice CS-4 were fully occupied.
* The other users can be explained in a similar way.

Example: 10 users, 5 stations, 3 time slots

Solution when the preference list is defined based on combination of minimum cost and distances

User = 1
[2, 1, 5]
[1, 2, 1]
[5, 4, 5]

User = 2
[5, 2, 1]
[1, 1, 1]
[3, 3, 3]

User = 3
[1, 4, 3]
[1, 3, 2]
[4, 5, 5]

User = 4
[3, 3, 1]
[3, 2, 2]
[4, 4, 4]

User = 5
[4, 1, 3]
[3, 2, 1]
[3, 7, 7]

User = 6
[4, 2, 5]
[1, 2, 2]
[4, 4, 4]

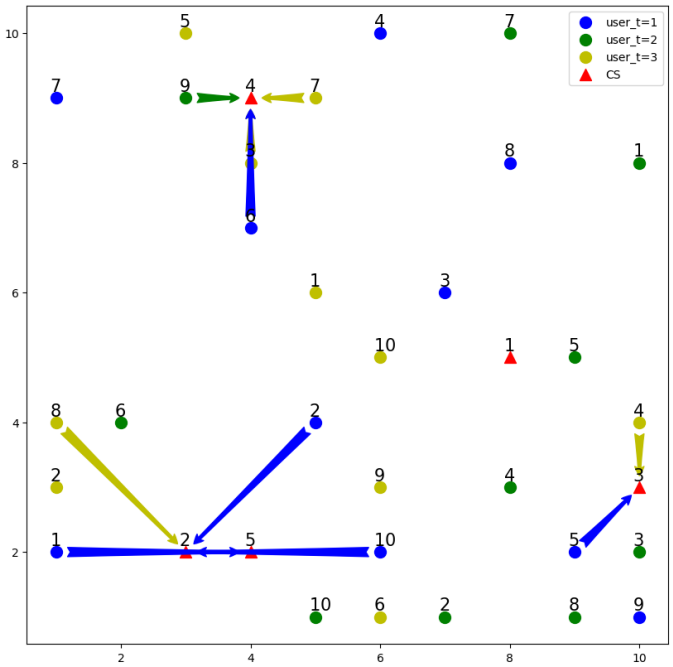
User = 7
[4, 4, 4]
[3, 2, 1]
[5, 3, 5]

User = 8
[2, 5, 1]
[3, 3, 1]
[3, 3, 4]

User = 9
[4, 5, 1]
[2, 3, 3]
[3, 3, 3]

User = 10
[5, 2, 1]
[1, 1, 1]
[3, 3, 3]

Initial
Preference list



Revenue
28

User obj value
17

Sizes
y_2=1
y_3=1
y_4=1
y_5=1

Prices
p_2_1 = 3
p_2_3 = 3
p_3_1 = 7
p_3_3 = 4
p_4_1 = 4
p_4_2 = 3
p_4_3 = 5
p_5_1 = 5

User = 1
[2, 0, 5]
[1, 0, 1]
[5, 0, 5]
x_1_5_1
p_5_1=5

User = 6
[4, 2, 5]
[1, 2, 2]
[4, 4, 4]
x_6_4_1
p_4_1=4

User = 2
[0, 2, 0]
[0, 1, 0]
[0, 3, 0]
x_2_2_1
p_2_1=3

User = 7
[4, 4, 4]
[3, 2, 1]
[5, 3, 5]
x_7_4_3
p_4_3=5

User = 3
[0, 4, 3]
[0, 3, 2]
[0, 5, 5]
x_3_4_3
p_4_3=5

User = 8
[2, 5, 0]
[3, 3, 0]
[3, 3, 0]
x_8_2_3
p_2_3=3

User = 4
[3, 3, 0]
[3, 2, 0]
[4, 4, 0]
x_4_3_3
p_3_3=4

User = 9
[4, 5, 0]
[2, 3, 0]
[3, 3, 0]
x_9_4_2
p_4_2=3

User = 5
[0, 0, 3]
[0, 0, 1]
[0, 0, 7]
x_5_3_1
p_3_1=7

User = 10
[0, 2, 0]
[0, 1, 0]
[0, 3, 0]
x_10_2_1
p_2_1=3

Updated
Preference list

Shoter arrows (distances) than the previous.
All users got their first avaiable CS choice.

Thanks for your attention!