Optimal Pricing for Efficient Electric Vehicle Charging Station Management

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Optimal Pricing for Efficient Electric Vehicle Charging Station Management

Motivation

Problem Statement

Conclusion

Problem Formulation

$$\min_{\mathbf{P}} SC$$
$$\text{s.t. } C_{ij}(\mathbf{x}, \mathbf{P}, \mathbf{s})p_{ij}(\mathbf{s}) \leq C_{ij}(\mathbf{x}, \mathbf{P}, \mathbf{s}')p_{ij}(\mathbf{s}), \forall i, j, \mathbf{s}, \mathbf{s}'$$

Experimental Results

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Experimental Results

Motivation

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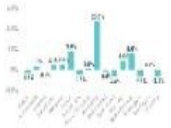
- Fast development of electric vehicles (EVs)

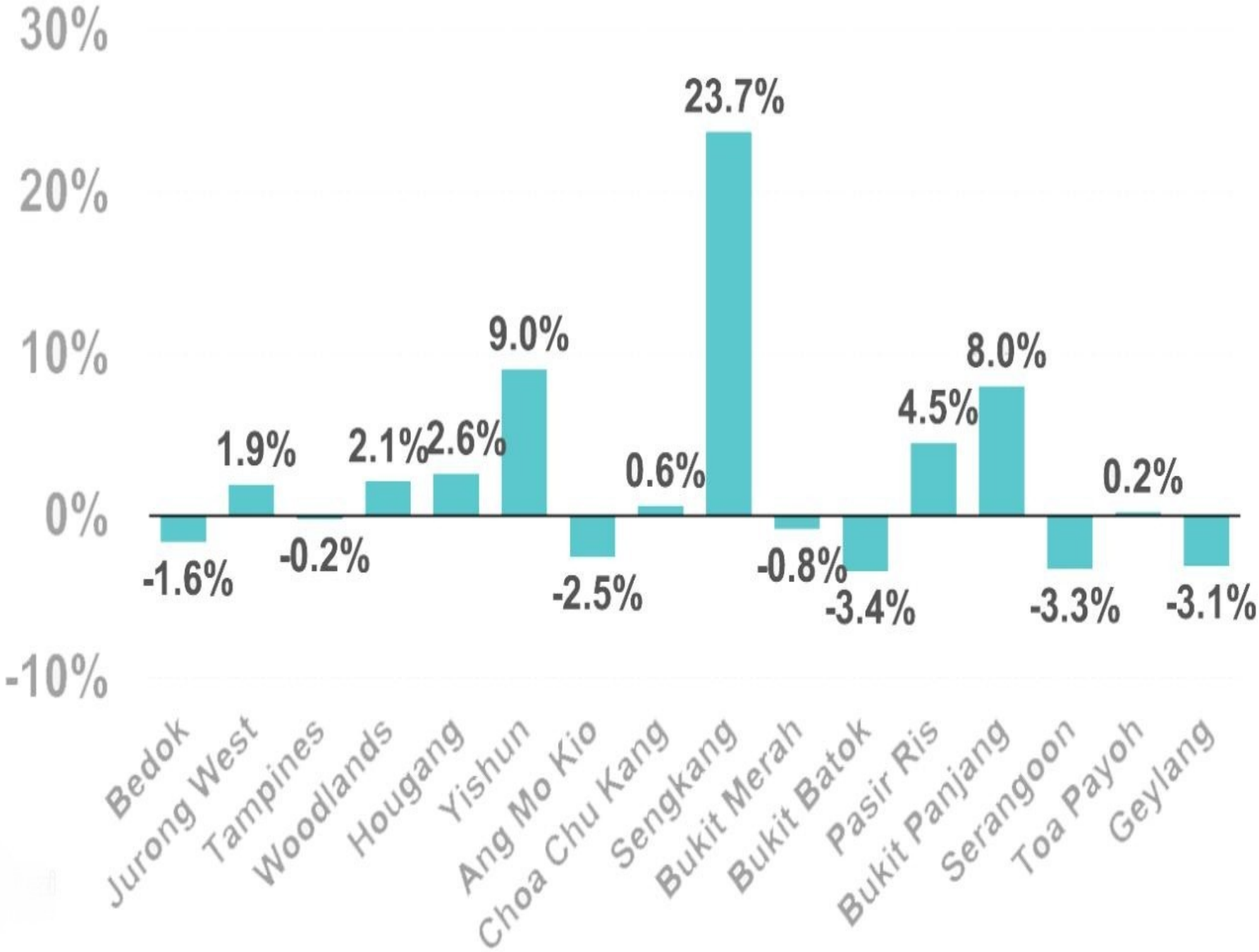
- Necessary of satisfying the charging demand

Charging station

Existing Works

> Most focus on the once-for-all solution

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Bedok
Jurong West
Tampines
Woodlands
Hougang
Yishun
Ang Mo Kio
Choa Chu Kang
Sengkang
Bukit Merah
Bukit Batok
Pasir Ris
Bukit Panjang
Serangoon
Toa Payoh
Geylang

Existing Works

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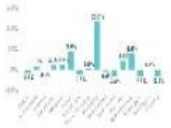

> Some use dynamic pricing to balance the power demand

> The traffic condition and users' selfish behavior are ignored

Problem Statement

Variables: The charging fare in each charging station

Objective: Minimize the total charging cost (social cost) of all EVs

Method: Game theoretic framework

Charging Game

Charging Game

- Region divided into zones

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- Player = EV user, whose driving pattern is a set of connected zones
- Strategy = choose one zone to charge

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1. Travel cost

- Charging cost

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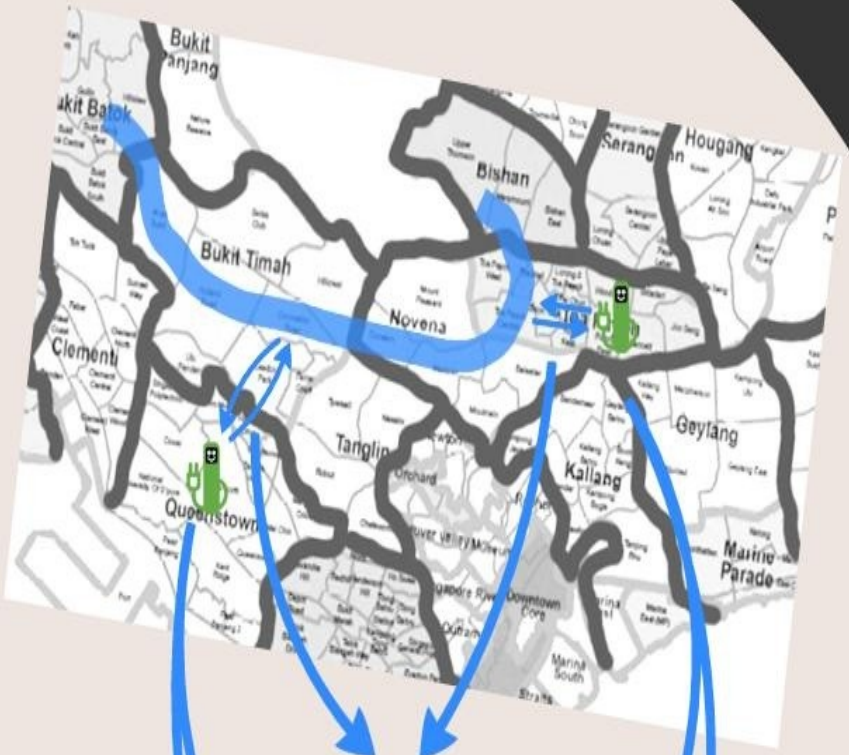


1. Travel cost
2. Queuing cost
3. Charging fee

- Charging cost

Charging Game

- Region divided into zones
- Player = EV user, whose driving pattern is a set of connected zones
- Strategy = choose one zone to charge
- Nash equilibrium in non-atomic congestion game

1. Travel cost
2. Queuing cost
3. Charging fee

- Charging cost

Problem Formulation

Social cost: all players' charging cost

$$\min_{\mathbf{x},\mathbf{P}} SC$$

$$\text{s.t. } C_{ij}(\mathbf{x},\mathbf{P},\mathbf{s})p_{ij}(\mathbf{s}) \leq C_{ij}(\mathbf{x},\mathbf{P},\mathbf{s}')p_{ij}(\mathbf{s}), \forall i,j,\mathbf{s},\mathbf{s}'$$

Non-linear constraints

Charging cost of strategy s

Probability of charging strategy s

Linear function of charging fee and strategies

$$\min_{\mathbf{x},\mathbf{P},\mathbf{y}} \quad SC$$

$$\text{s.t.} \quad y_{ij}(\mathbf{s})C_{ij}(\mathbf{P},\mathbf{s}) \leq y_{ij}(\mathbf{s})C_{ij}(\mathbf{P},\mathbf{s}'),$$
$$\forall i \in \mathcal{Z}, \forall j \in \mathcal{K}_i, \forall \mathbf{s},\mathbf{s}' \in \mathcal{S}_{ij}$$

$$p_{ij}(\mathbf{s}) \leq y_{ij}(\mathbf{s}), \ \forall i \in \mathcal{Z}, j \in \mathcal{K}_i, \mathbf{s} \in \mathcal{S}_{ij}$$

$$y_{ij}(\mathbf{s}) \in \{0,1\}, \ \forall i \in \mathcal{Z}, j \in \mathcal{K}_i, \mathbf{s} \in \mathcal{S}_{ij}$$

- Initiate the support (indicator y)
- Compute the equilibrium
- Update the support

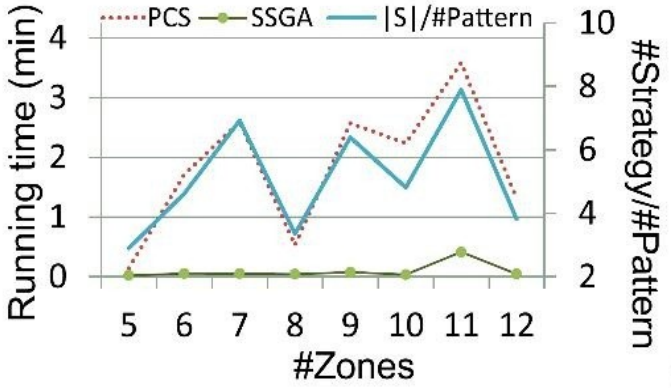
Experimental Results

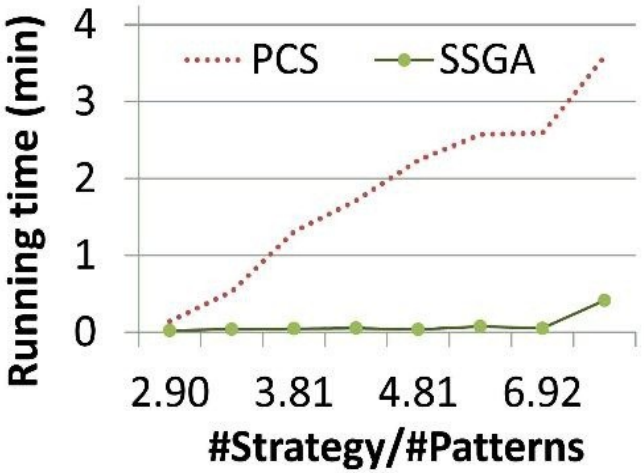
Runtime and social cost

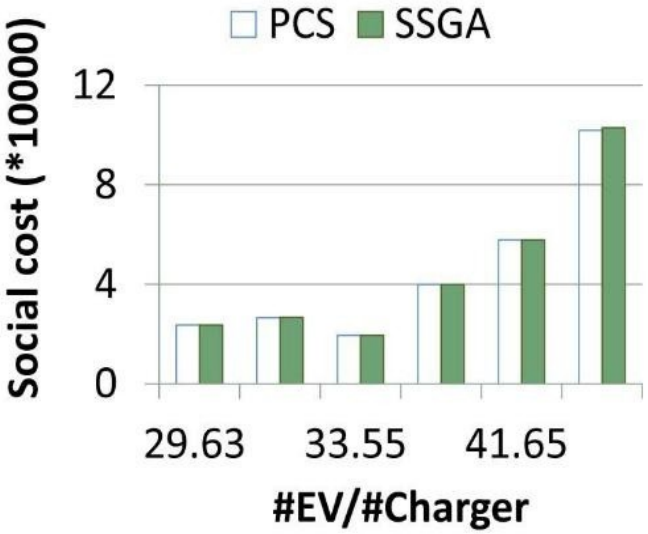
Comparison with uniform pricing

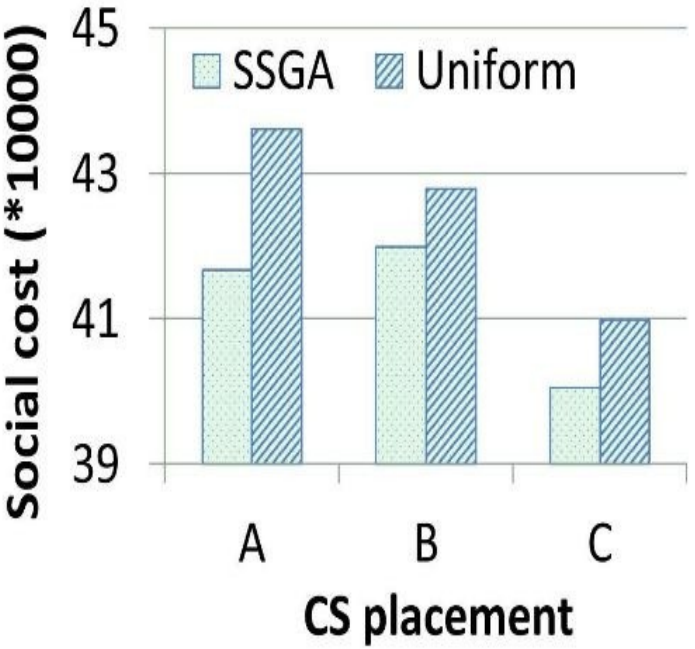
Robustness

Runtime and social cost

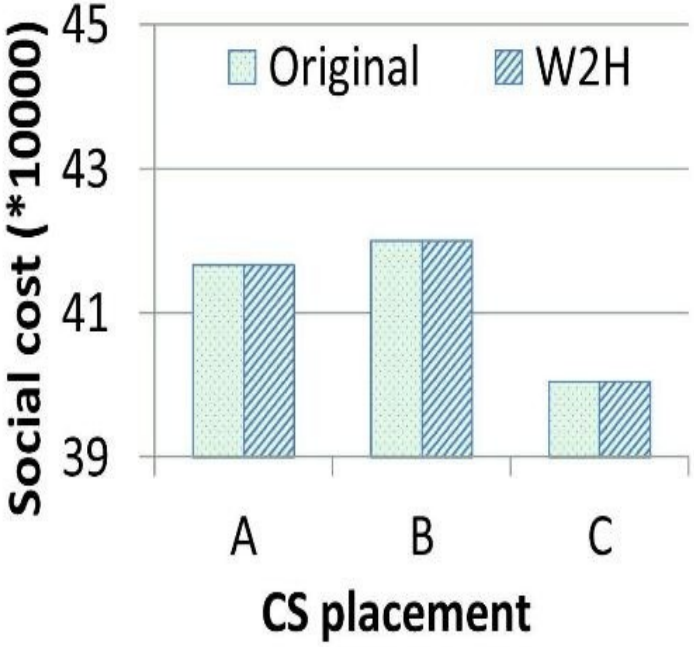






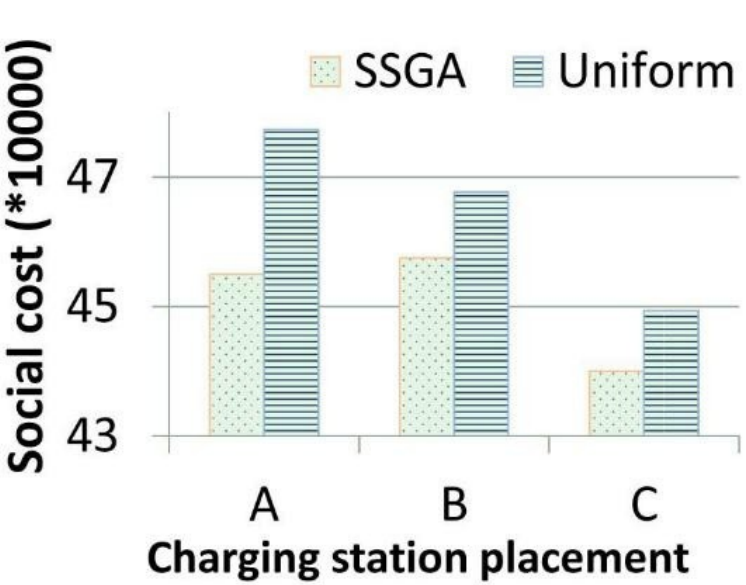


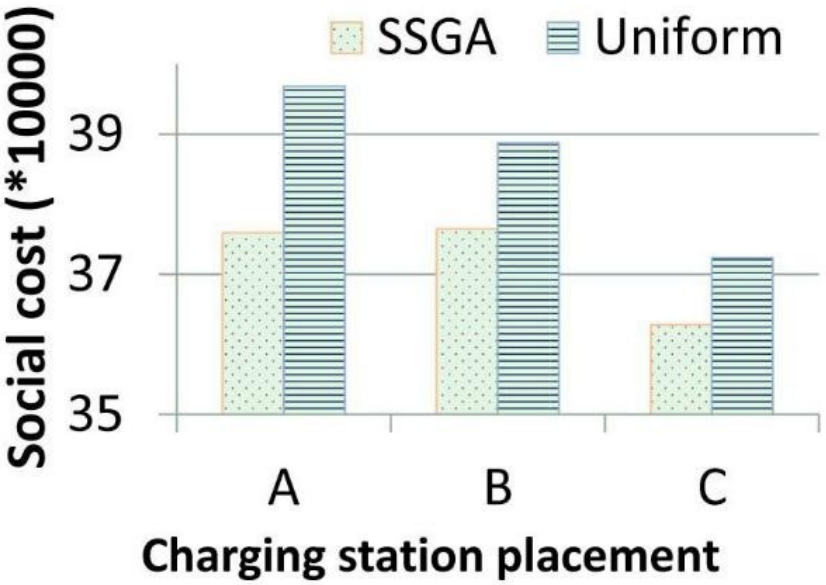
Comparison with uniform pricing



When consider 2-step hop charging

Robustness





#of EV Users +5%

# of EV Users -5%

Conclusion

- Novel pricing model that incorporates:
  1. EV users' strategic charging behavior
  2. Traffic congestion
  3. Financial concern
- Strategy space generation algorithm that can efficiently speed up the computation
- Extensive experiments that prove our approach can effectively reduce the social cost

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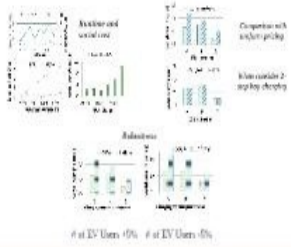

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Thank You