Electrical Vehicle Charging Station Deployment based on Real World Vehicle Trace

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IOV
Nadi, Fiji
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Why is electric vehicle necessary?

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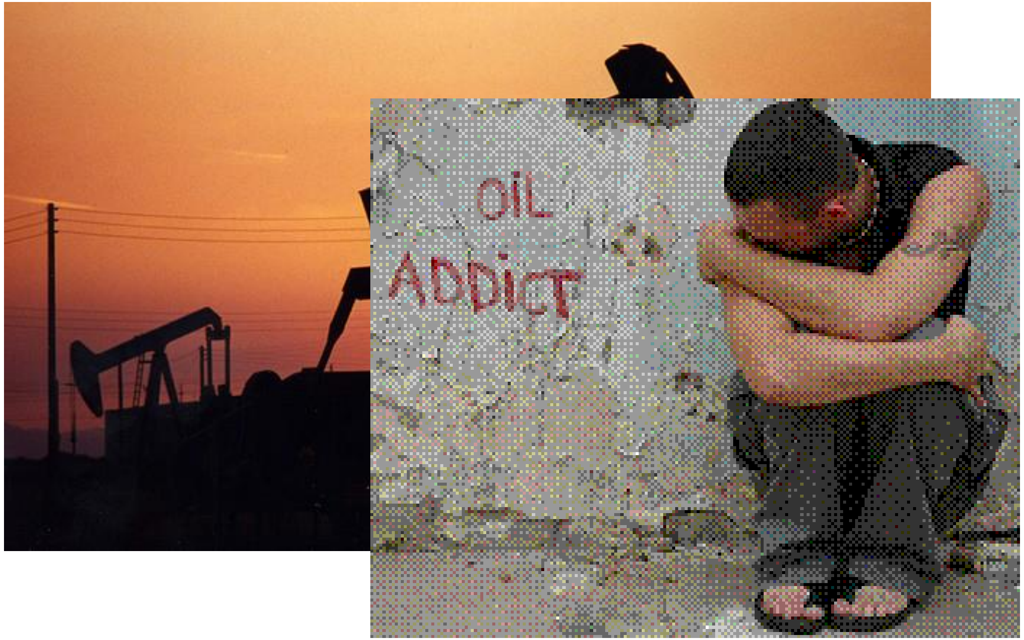

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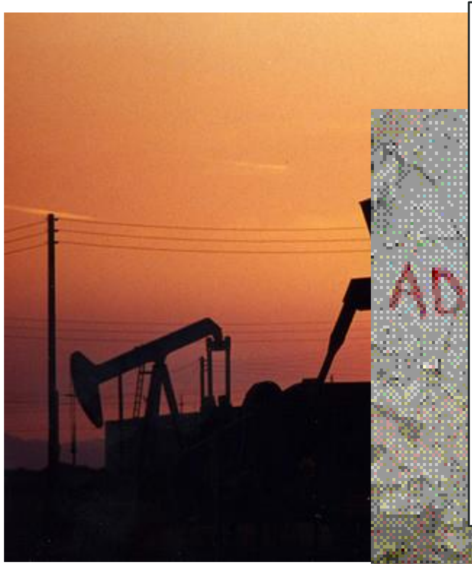

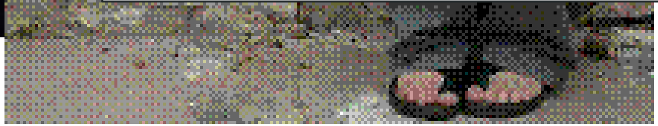

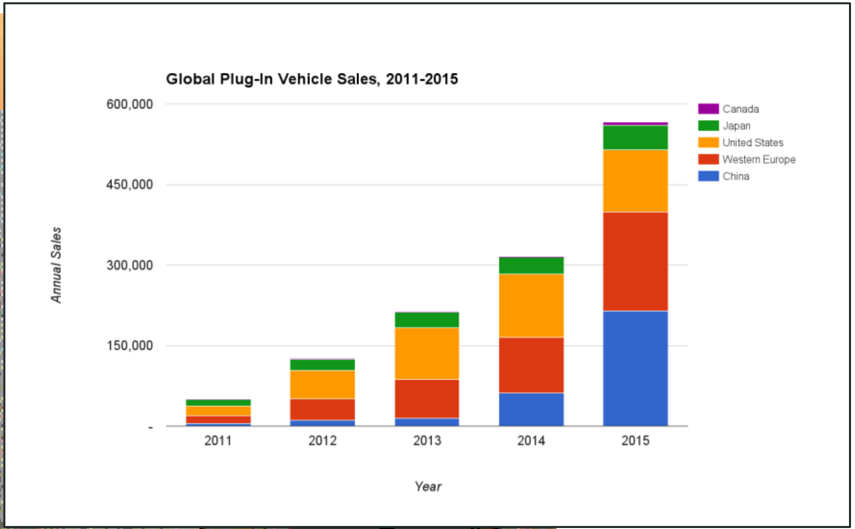

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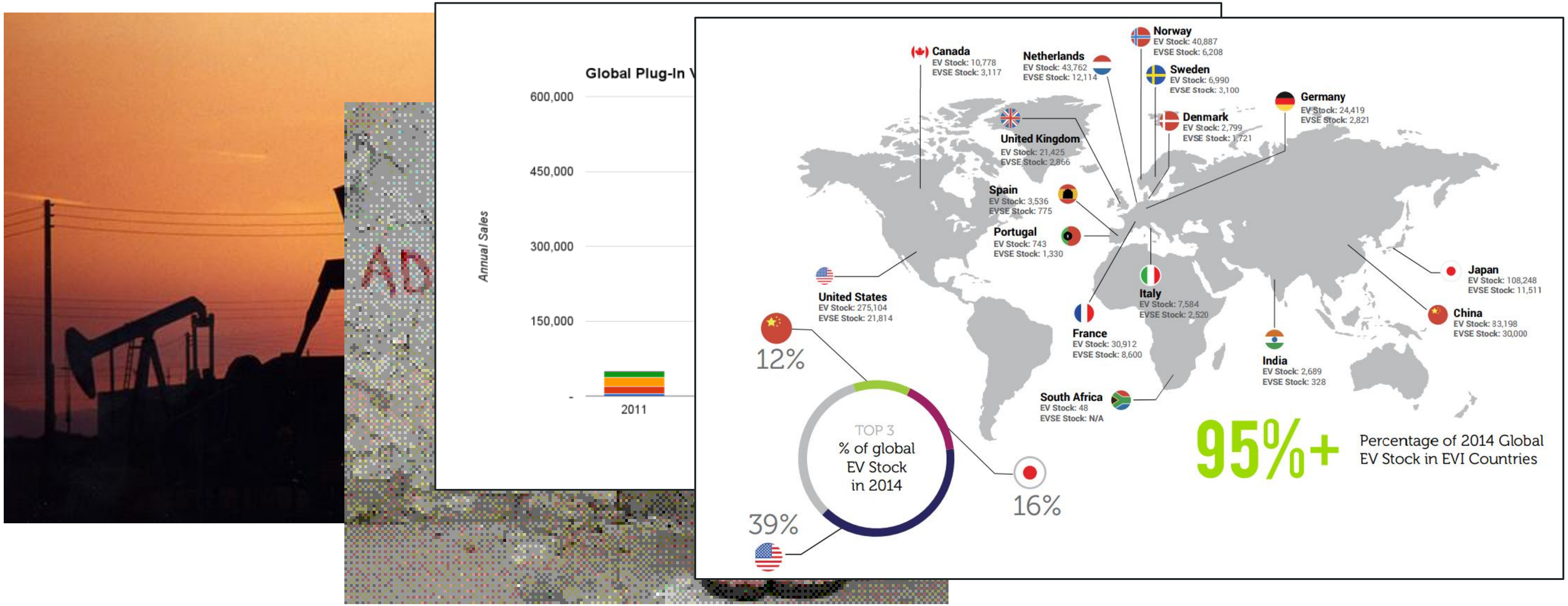

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1

Charging demand based methods

- IEEE Transactions on Smart Grid, VOL. 3, NO. 1
- IEEE IEVC'14
- IEEE Transactions on Power Systems, VOL. 29, NO. 1

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1

Charging demand based methods

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2

Traffic flow based methods

- IEEE Transactions on Smart Grid, VOL. 5, NO. 6
- IEEE Transactions on Power Systems, VOL. 27, NO. 3
- IEEE Transactions on Power Delivery, VOL. 28, NO. 4

Problems

1

Charging demand based methods

Demand deduced by the proposed means cannot depict the actual charging scenario of the whole road network due to several factors

2

Traffic flow based methods

The design is only validated with datasets of small scenarios

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EVReal: Deploying Charging Stations for EVs considering Real-world vehicle trace

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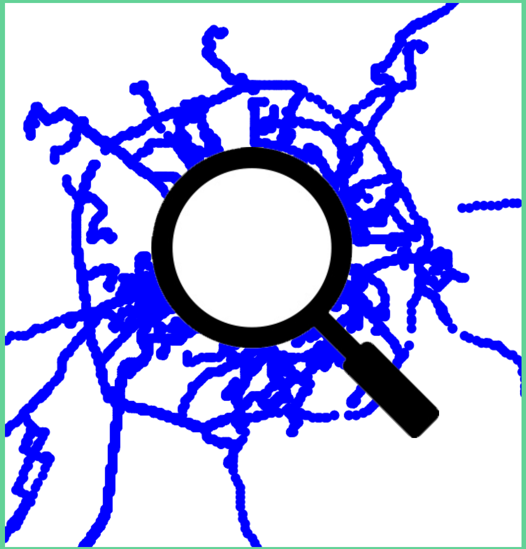
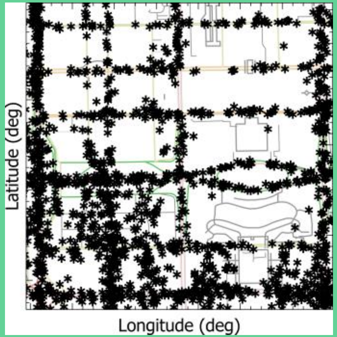
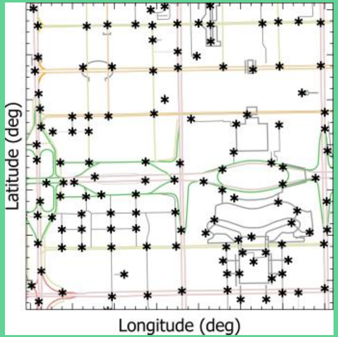






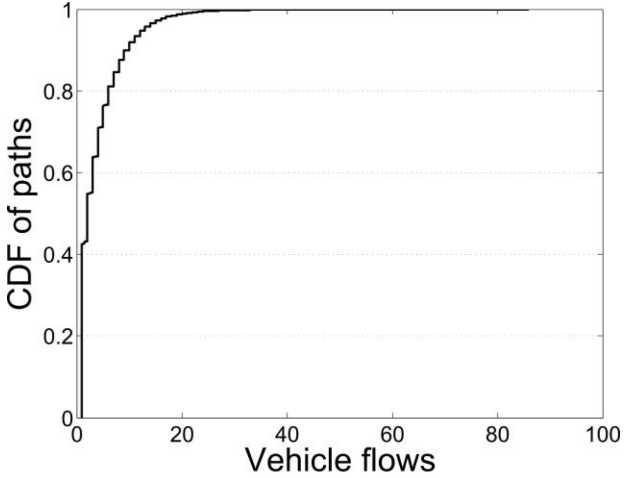
Overview

Trace analysis and supportive findings for EVReal

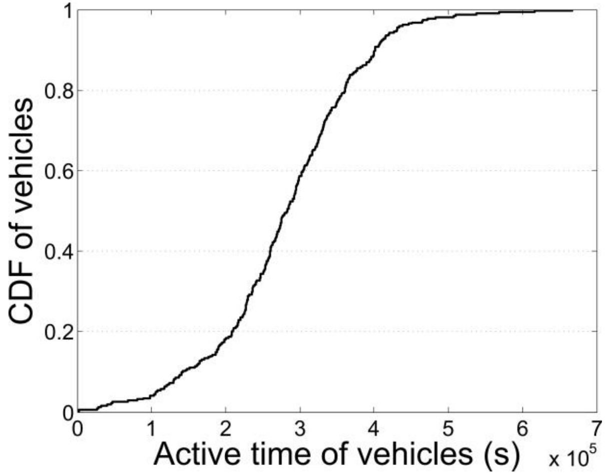
System Design of EVReal

Performance Evaluation

Conclusion with future directions



CDF of paths
Vehicle flows
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80
100



CDF of vehicles
Active time of vehicles (s)
x 10^5
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7

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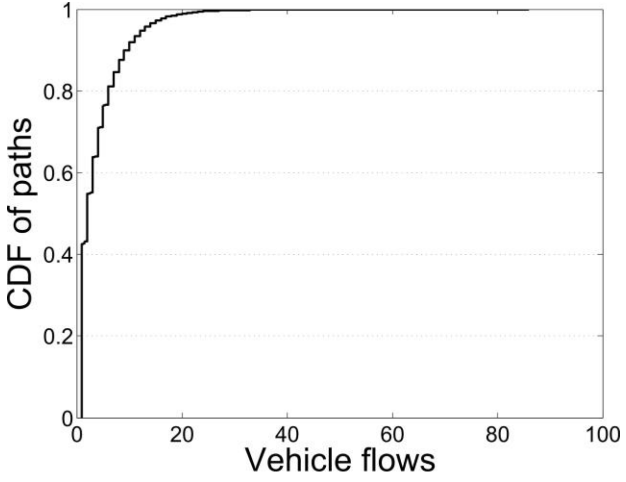
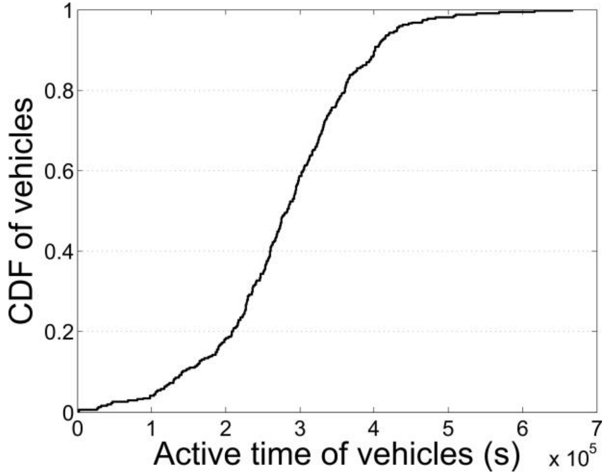
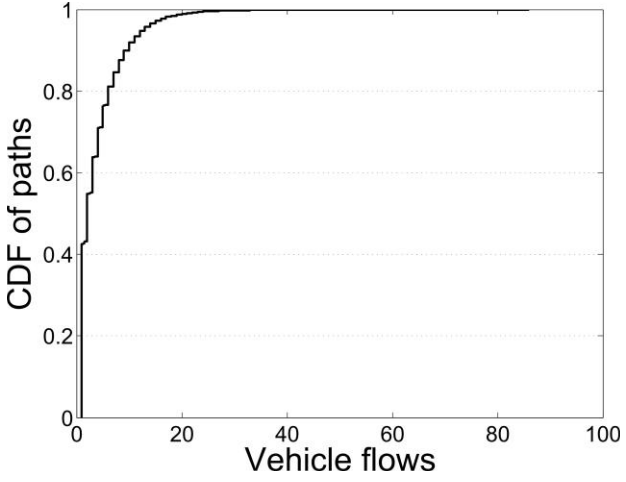
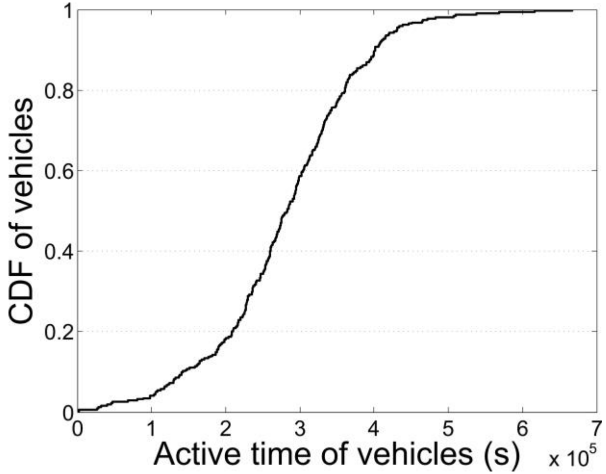




Most of the trajectories have vehicle flows lower than 15. The largest traffic flow is higher than 80.

Vehicles' activities concentrate at certain popular areas





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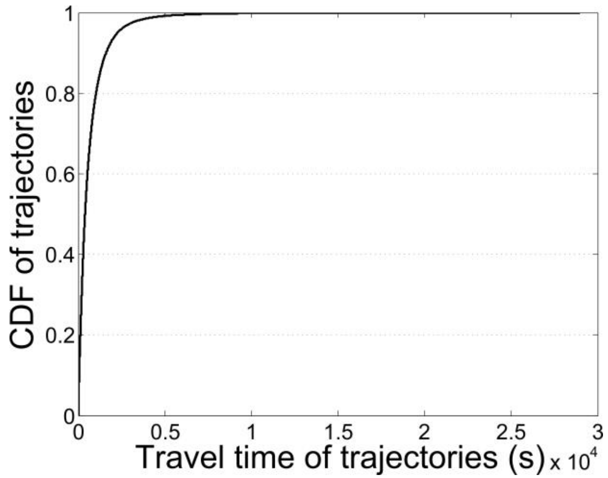
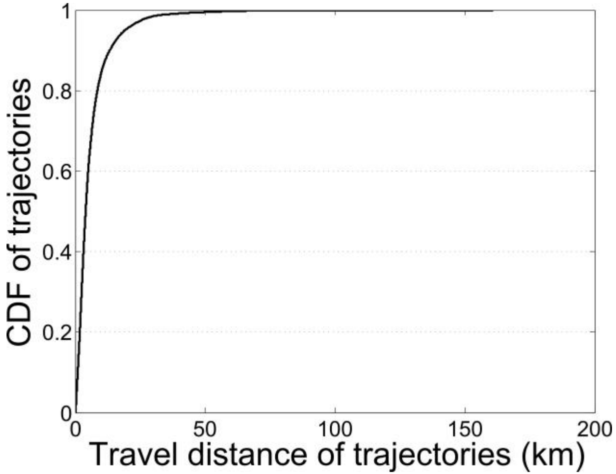
Vehicles' activities concentrate at certain popular areas

Vehicles have fluctuating active time

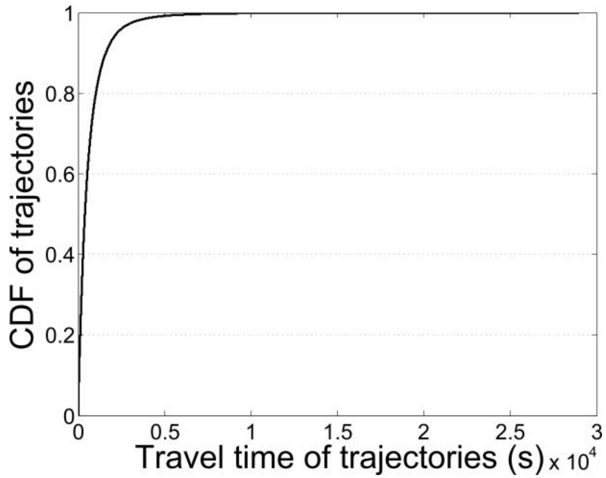
Comprehensively collecting the traffic flows is crucial

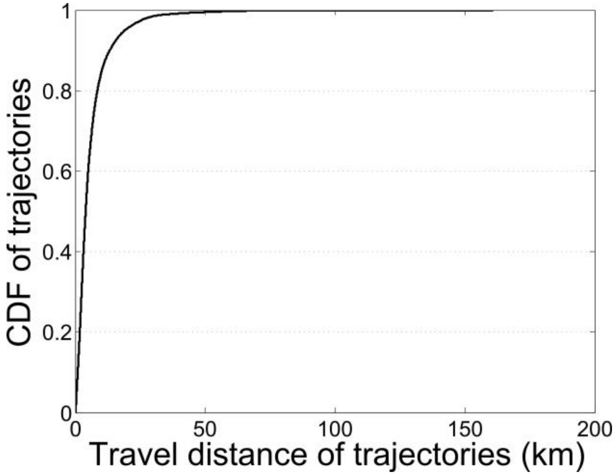


CDF of trajectories
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
Travel time of trajectories (s)
x 10^4



CDF of trajectories
0
0.2
0.4
0.6
0.8
1
0
50
100
150
200
Travel distance of trajectories (km)

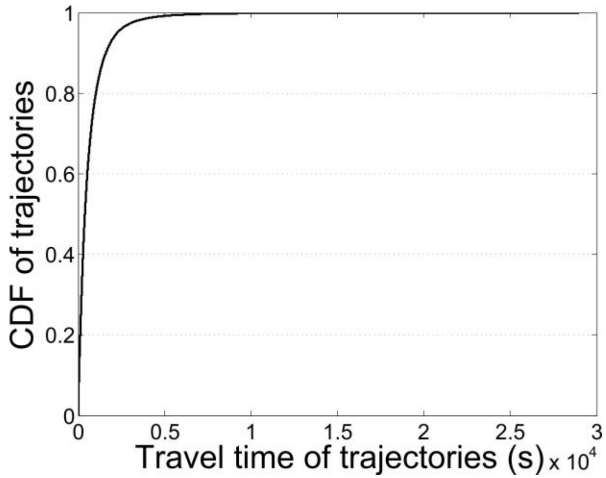


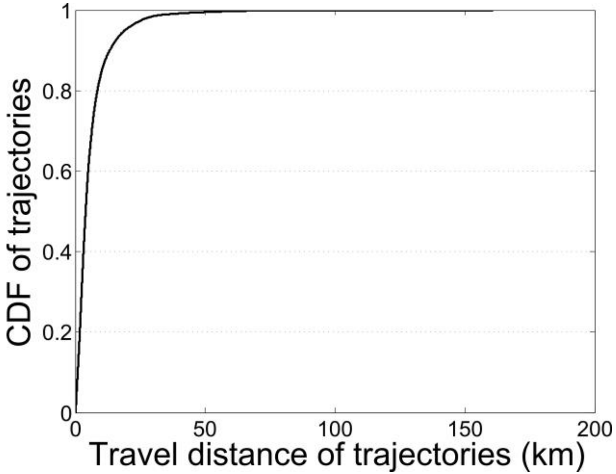


Vehicles' travel durations are often less than 5min

↓

The time to reach the nearest charging stations should be shorter than most travel durations.





Vehicles' travel durations are often less than 5min

The time to reach the nearest charging stations should be shorter than most travel durations.

Vehicles' travel distances are often less than 20km

The distance to the nearest charging stations should be shorter than most travel distances

Formulation of constraints

- Vehicle flows are highly concentrated within certain ranges → Maximize the totally captured vehicle flows
- Vehicles' active times fluctuate → Collect vehicle traffic flow statistics and determine which flow the charging stations should cover
- Vehicles travel short distance and duration → We assume a vehicle can be charged as long as there's a charging station at that position
- Additional constraints → Installation cost per station, total budget, battery capacity

Model formulation

To maximize the captured traffic flow:

Model formulation

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$$\max \sum_{r,s} Y^{rs} f^{rs}$$

Model formulation

To maximize the captured traffic flow:

$$\max \sum_{r,s} Y^{rs} f^{rs}$$

$Y^{rs} = 1$ if the path between r and s can be taken, $Y^{rs} = 0$ otherwise

f^{rs} is the traffic flow from r to s

Model formulation

EV battery capacity constraint:

$$B_i^{rs} + l_i^{rs} \leq M(1 - Y^{rs}) + \beta, \ \forall r, s; i \in P^{rs}$$

B_i^{rs} is the remaining range at landmark i on the path of O-D pair $r - s$

l_i^{rs} is the amount of energy recharged at landmark i on the path of O-D pair $r - s$

Model formulation

Energy consumption conservation constraint:

$$B_i^{rs} + l_i^{rs} - d_{ij} - B_j^{rs} \le M(1 - Y^{rs}),$$
$$\forall r, s; i, j \in P^{rs}; (i, j) \in A$$
$$-(B_i^{rs} + l_i^{rs} - d_{ij} - B_j^{rs}) \le M(1 - Y^{rs}),$$
$$\forall r, s; i, j \in P^{rs}; (i, j) \in A$$

d_{ij} Distance between landmark i and landmark j

P^{rs} A sequence of landmarks on the shortest path from r to s

Model formulation

Charging availability constraint:

$$\sum_{r,s} l_i^{rs} \delta_i^{rs} \leq M X_i, \ \forall i \in \hat{N}$$

δ_i^{rs} indicates whether landmark i is in the sequence of landmarks P^{rs}

X_i indicates whether there is a charging station at landmark i

Model formulation

Budget constraint:

$$\sum_i C_i X_i \leq m$$

C_i is the installation cost of a charging station

Performance evaluation

Vehicle mobility traces

Performance evaluation

Vehicle mobility traces

Rome: 30-day taxi trace with 315 taxis and 4638 landmarks

Performance evaluation

Vehicle mobility traces

Rome: 30-day taxi trace with 315 taxis and 4638 landmarks

R. Amici, M. Bonola, L. Bracciale, P. Loreti, A. Rabuffi, and G. Bianchi, "Performance assessment of an epidemic protocol in VANET using real traces," in Proc. of MoWNeT, 2014.

Performance evaluation

Assumptions for determining the charging stations:

- Installation cost is identical for each charging station
- All vehicles are homogeneous
- All drivers are homogeneous

Performance evaluation (cont.)

Deployment of charging stations under different budget

sites	Deployment of charging stations (Landmark ID)		sites	Deployment of charging stations (Landmark ID)	
	VR=50km	VR=100km		VR=50km	VR=100km
1	3197	2558	7	5, 136, 262, 374, 741, 2957, 3197	-
2	14, 3197	-	8	5, 86, 136, 374, 382, 485, 615, 3197	-
3	14, 136, 3197	-	9	5, 136, 262, 374, 485, 741, 1782, 2980, 3197	-
4	14, 136, 374, 3197	-	10	5, 86, 136, 374, 485, 741, 1097, 1782, 2980, 3197	-
5	86, 136, 374, 382, 3197	-	11	5, 9, 136, 262, 374, 484, 485, 570, 624, 2980, 3060	-
6	136, 262, 374, 741, 2957, 3197	-			

Performance evaluation (cont.)

Coverage of flows under different budget scenarios

sites	Captured traffic flows		sites	Captured traffic flows		sites	Captured traffic flows	
	VR=50km	VR=100km		VR=50km	VR=100km		VR=50km	VR=100km
1	640619	645047	5	644386	-	9	644975	-
2	642058	-	6	644786	-	10	645010	-
3	643048	-	7	644875	-	11	645047	-
4	643830	-	8	644959	-			

Performance evaluation (cont.)

Metrics

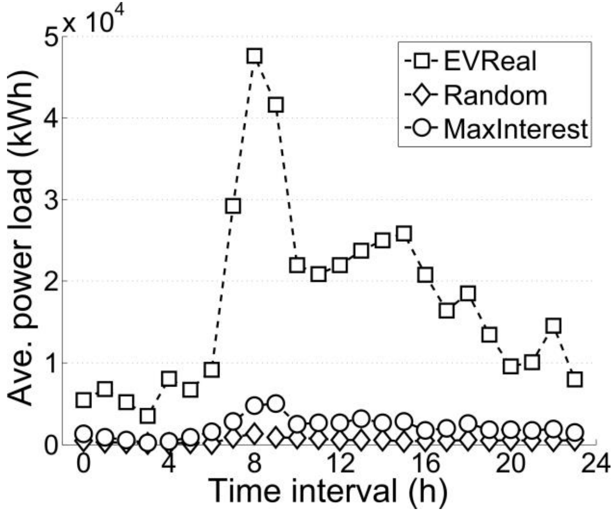
- Average charging station power load
- Average vehicle residual energy
- Average number of necessary charges
- Average travel time to the nearest charging stations

Performance evaluation (cont.)

Ave. station power load + Ave. vehicle residual power:

Performance evaluation (cont.)

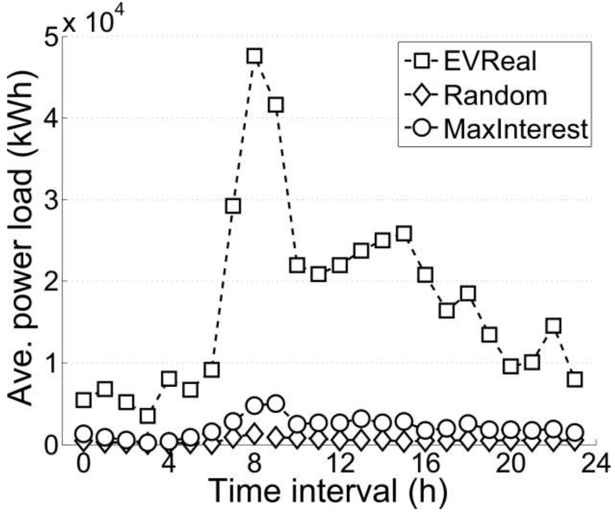
Ave. station power load + Ave. vehicle residual power:



MaxInterest>EVReal>Random

Performance evaluation (cont.)

Ave. station power load + Ave. vehicle residual power:



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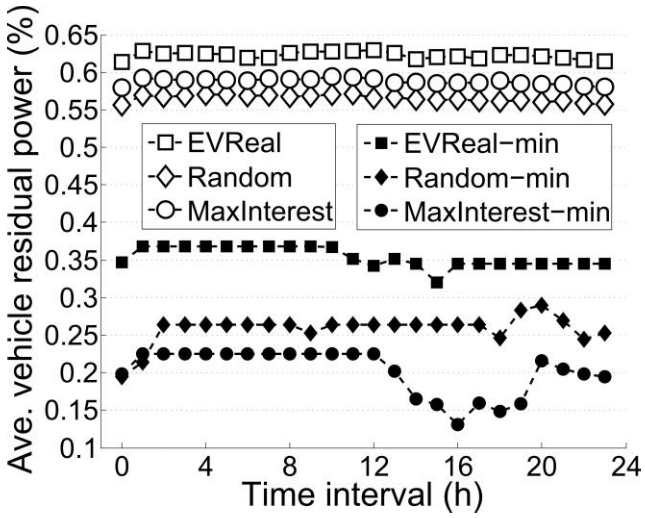

EVReal>MaxInterest>Random

Performance evaluation (cont.)

Ave. number of charges + Ave. time to charging stations:

Performance evaluation (cont.)

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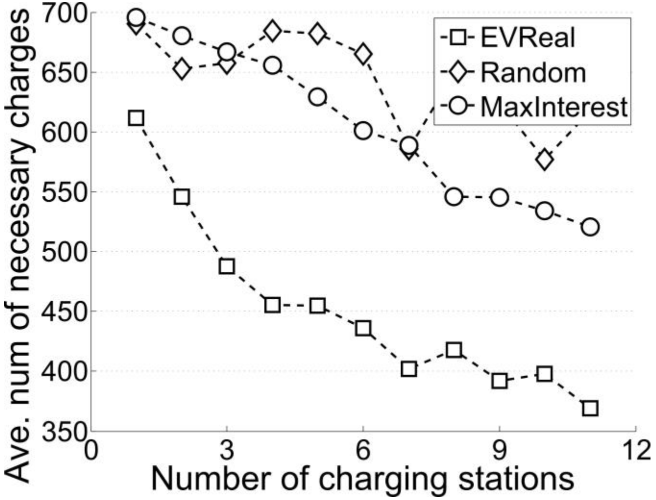
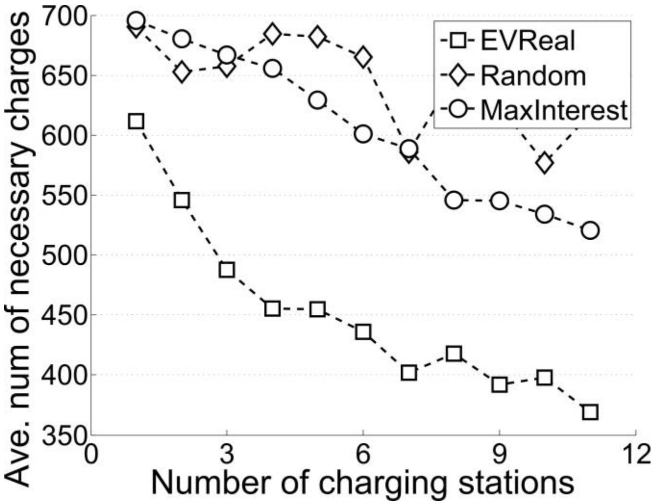


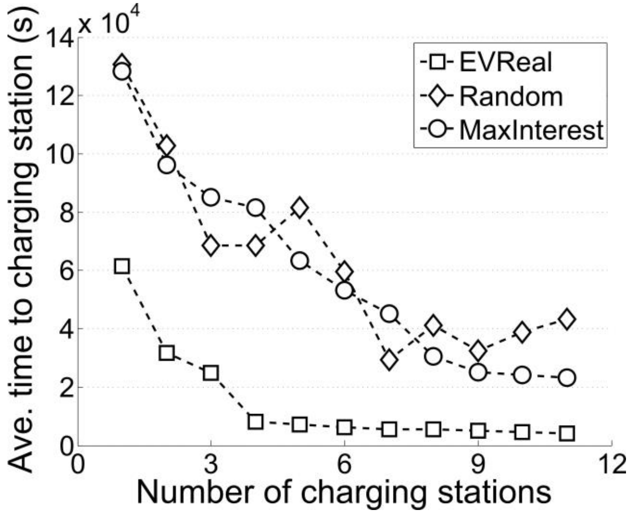
Random>MaxInterest>EVReal

Performance evaluation (cont.)

Ave. number of charges + Ave. time to charging stations:



Random>MaxInterest>EVReal



MaxInterest $\approx$ Random>EVReal

Conclusions

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1. Extensive trace analysis is helpful for finding the necessary constraints for consideration.

2. The formulated optimization model considers various constraints and its performance is verified to be better than other methods.

3. Majority of the vehicles have social patterns, which may be exploited to further improve the performance of planning charging stations.

Thank you!
Questions & Comments?

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