TOP: Vehicle Trajectory based Driving Speed Optimization Strategy for Travel Time Minimization and Road Congestion Avoidance

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Why is traffic congestion control pivotal?

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UNIVERSITY of VIRGINIA

Why is traffic congestion control pivotal?

1

Use signal to schedule passing of vehicles

University of Virginia

1

Use signal to schedule passing of vehicles

2

Use vehicle's driving info to optimize speed

Problem

Problem

Overlook the possible road congestion generation in the future

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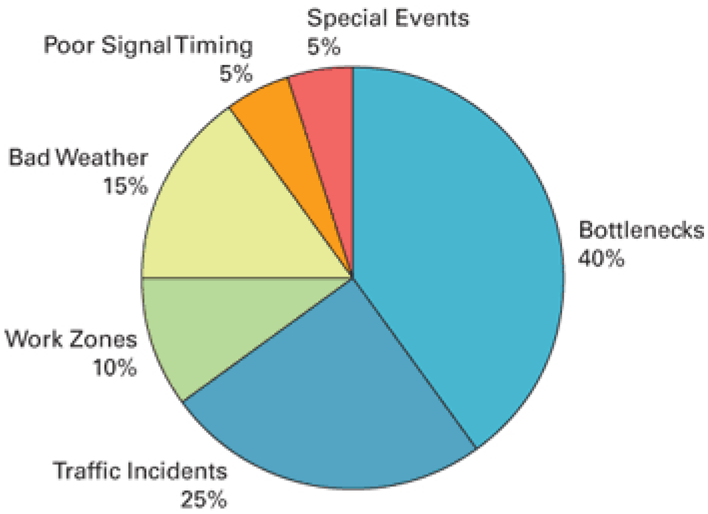

http://ops.fhwa.dot.gov/publications/fhwahop09015/cp_prim7_02.htm

Problem

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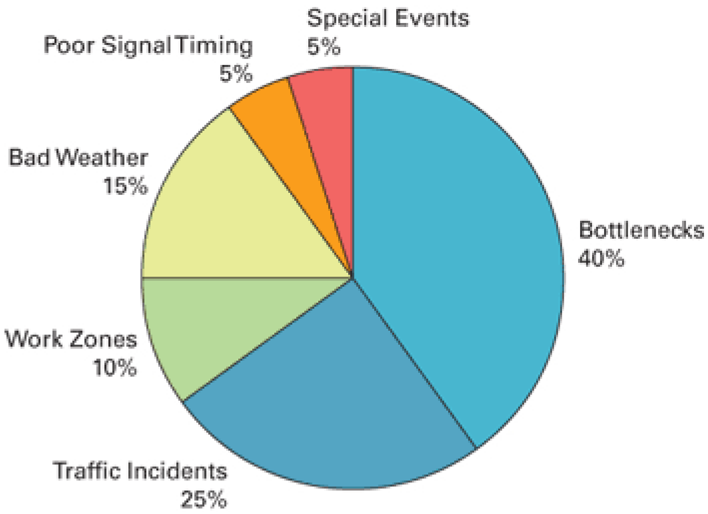

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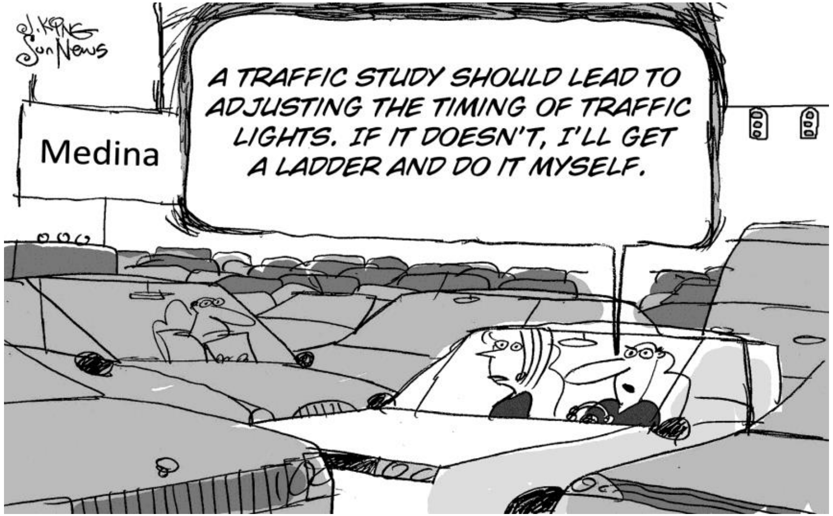

http://www.cleveland.com/medina/index.ssf/2011/12/traffic_congestion_in_medina_e.html

University of Virginia

TOP: Trajectory based speed OPtimization

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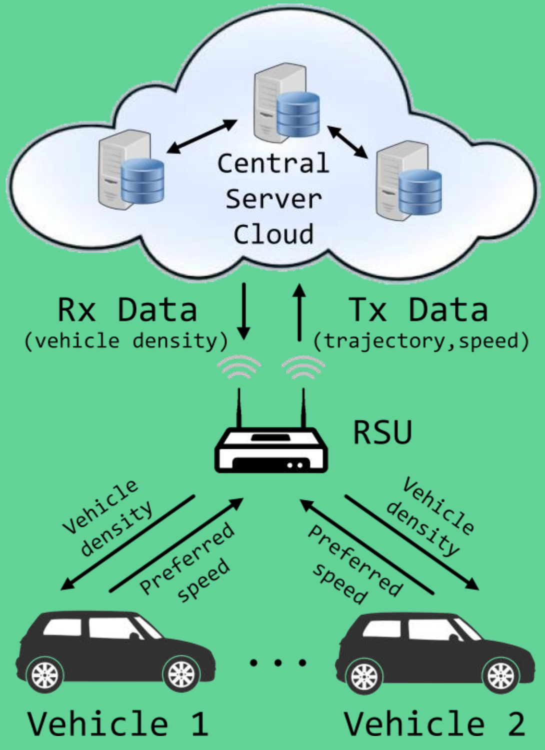
Adjust vehicles' mobility to alleviate road congestion globally



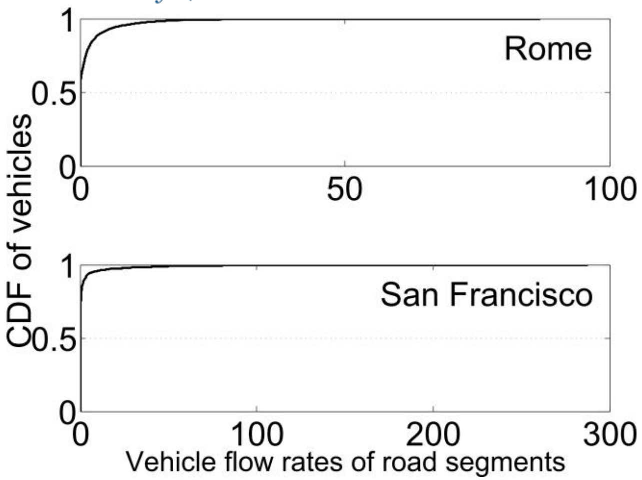
Overview

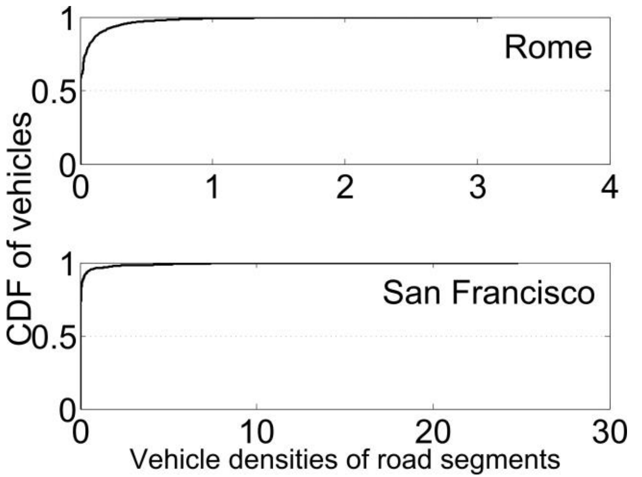
Trace analysis and supportive findings for TOP

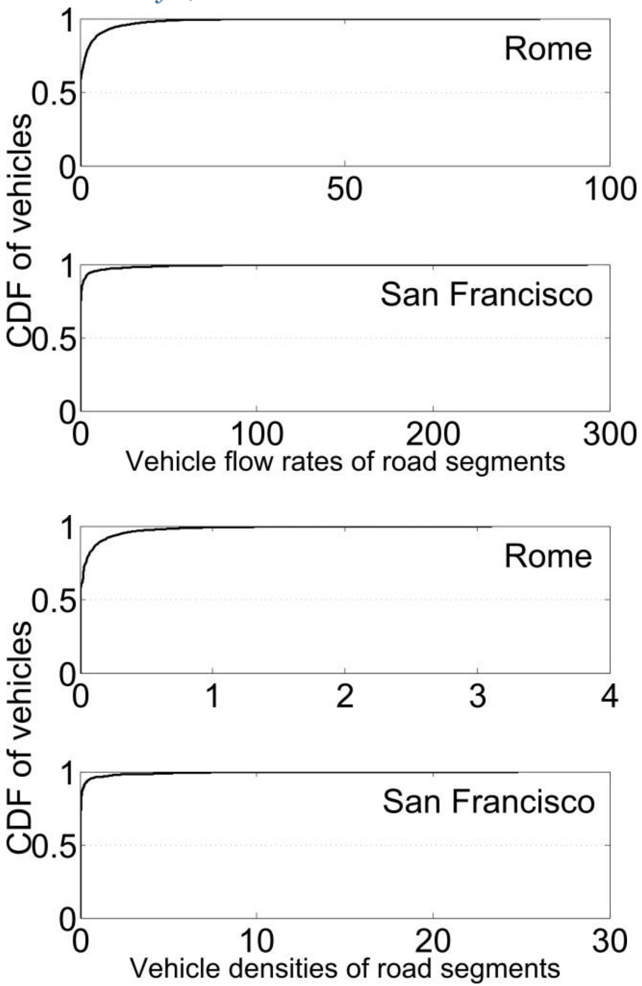
Design of TOP

Experimental results

Conclusion with future directions


Rome
San Francisco
CDF of vehicles
1
0.5
0
0
50
100
100
200
300
Vehicle flow rates of road segments


Rome
San Francisco
CDF of vehicles
1
0.5
0
0
1
2
3
4
10
20
30
Vehicle densities of road segments



Vehicles' concurrent competition for few popular roads

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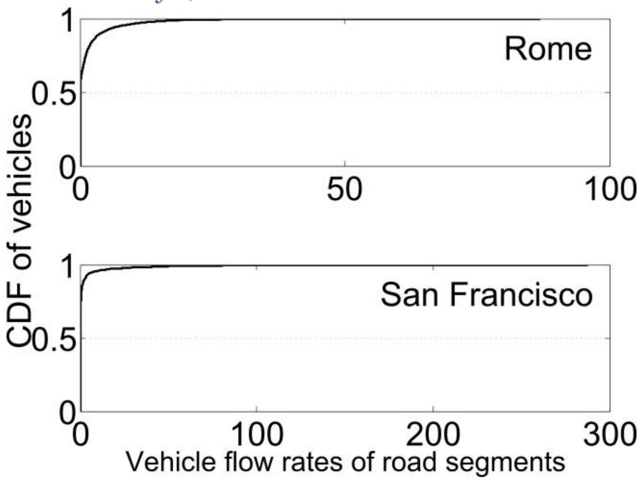
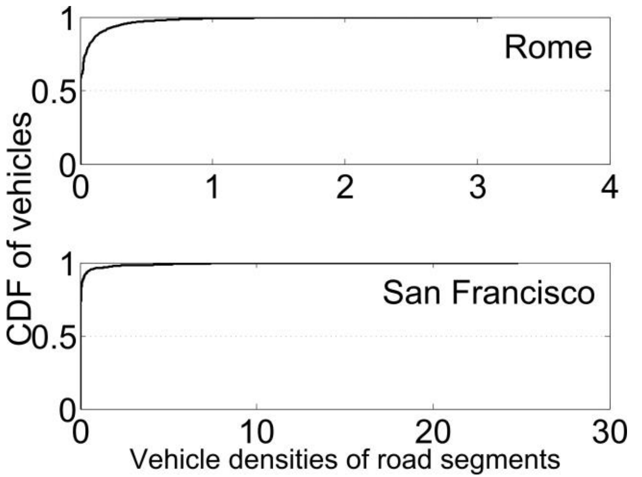
Excessive usage of the roads



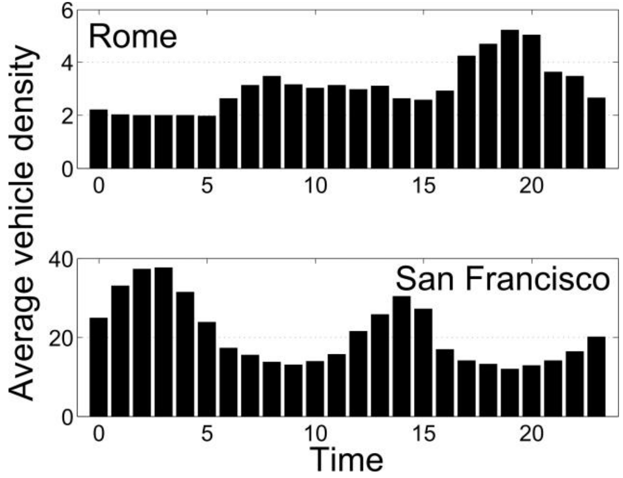


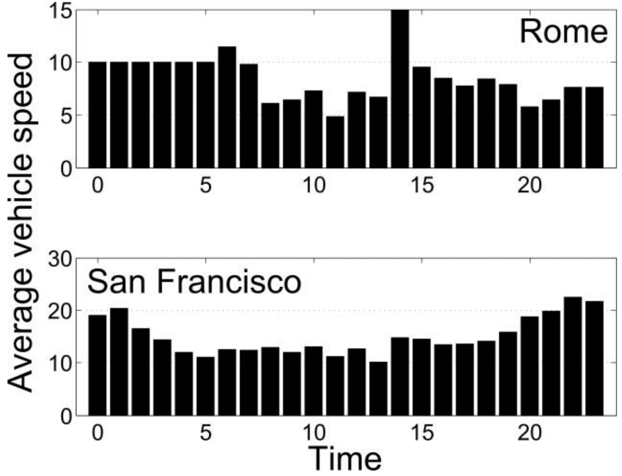
Vehicles' concurrent competition for few popular roads

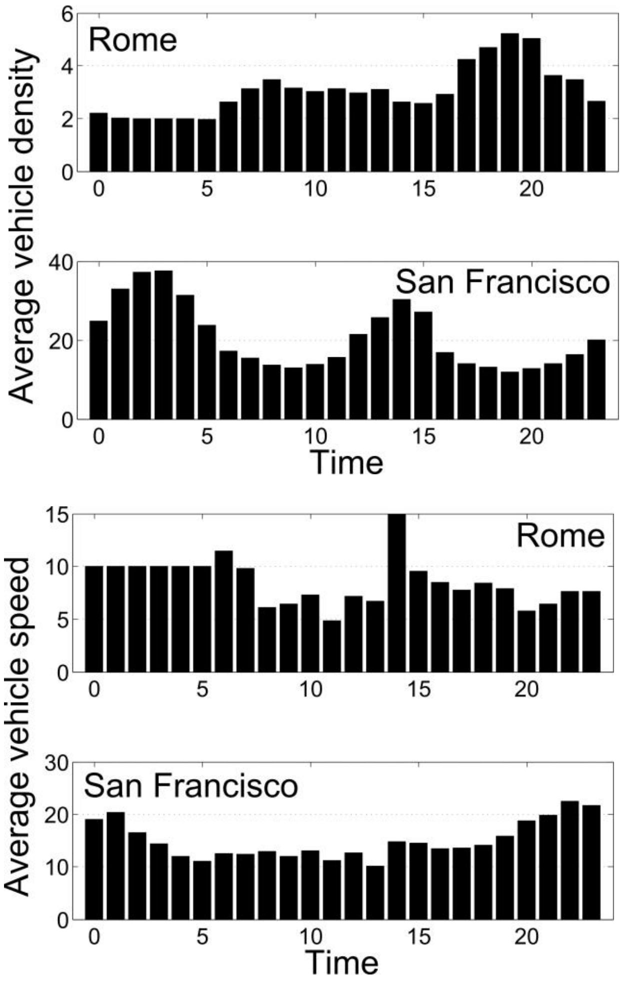
Excessive usage of the roads

Distribute vehicle traffic evenly in all road segments

Avoid road congestion and increase the utilization of road network

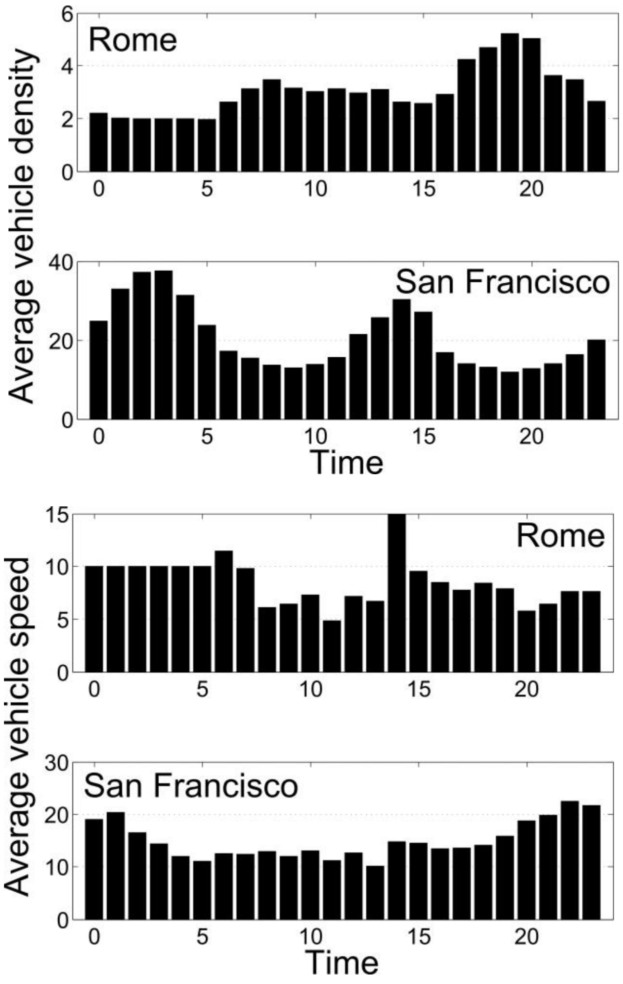

Average vehicle density
Rome
San Francisco
Time


Average vehicle speed
Rome
San Francisco
Time



Vehicles' temporal preference on roads

High vehicle density during some times



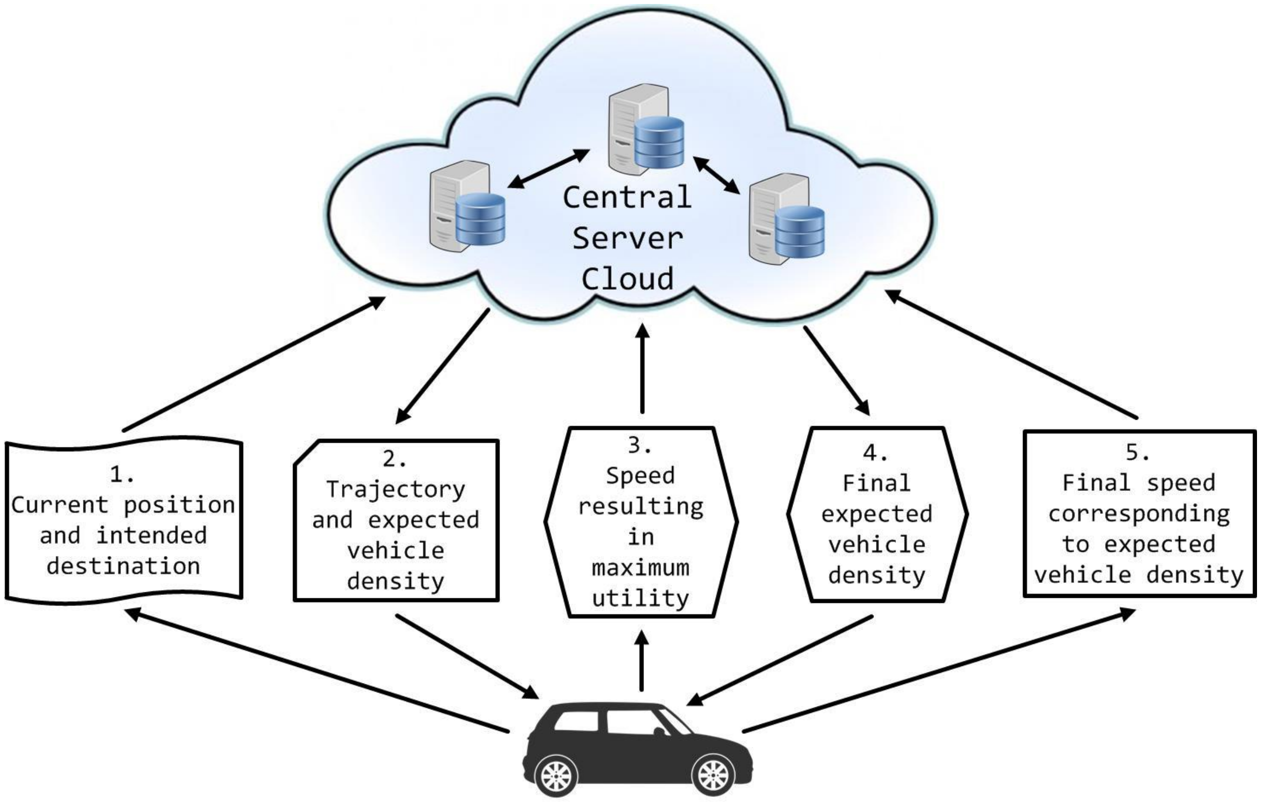
Vehicles' temporal preference on roads

High vehicle density during some times

Allocate the usage of roads to different time slots

Avoid high vehicle density during some times (e.g., rush hours)

Gaming process



Future vehicle density prediction

Trajectory calculation

For a road segment:

Estimated total travel time:

Future vehicle density prediction

Trajectory calculation

For a road segment:

$$t_i = \begin{cases} l_i / v_i^{\max}, & 0 \le d_i < d_i^m \\ l_i / v_i^{\min}, & d_i^m \le d_i < d_i^{jam} \\ \infty, & d_i \ge d_i^{jam} \end{cases}$$

Estimated total travel time:

$$T_i = \sum_{m=1}^{M_i} t_m$$

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Travel times follow normal distribution, and are i.i.d.

Future vehicle density prediction

Road vehicle density calculation

For a road segment: $$d_{i+1}^{s_i} = \sum_{k=1}^{N} P_k(T_i \leq t_j^e - t_j^s)$$

N is the number of vehicles that will pass s_i during $\left[t_j^e, t_j^s\right]$

Future vehicle density prediction

Safety estimation

For a road segment: $$p_i^j = \frac{\sum_{w=1}^{W} T_j^w}{W(t_j^e - t_j^s)}$$

which is the accident probability of s_i during the j th interval

For central server:

$$L(d) = \sum_{i=1}^{N_S} d_i \cdot v_i$$

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For drivers:

$$F(v_i, a_i, p_i^j) = U_s(v_i, a_i, p_i^j) - U_r(d, v_i, p_i^j)$$
$$= \alpha_i \ln(v_i + p_i^{j-1}) - p_i^j d v_i$$

$$\sum_i \gamma_i F(v_i, \alpha_i, p_i^j)$$
$$\text{s.t.} \quad v_i \le v_i^{\max}$$

Driving speed optimization gaming

1. The central server offers densities:

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4. Each vehicle updates speed according to the new vehicle density

Performance evaluation

Vehicle mobility traces

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- Rome [1]: 30-day taxi trace with 315 taxis and 4638 landmarks

Performance evaluation

Vehicle mobility traces

- Rome [1]: 30-day taxi trace with 315 taxis and 4638 landmarks
- San Francisco [2]: 30-day taxi trace with 536 taxis and 2508 landmarks

[1] 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.
[2] M. Piórkowski, N. Sarafijanovic-Djukic, and M. Grossglauser, “A parsimonious model of mobile partitioned networks with clustering,” in Proc. of COMSNETS, 2009.

Performance evaluation (cont.)

Metrics

Performance evaluation (cont.)

Metrics

- Average vehicle speed
- Average flow rate
- Average driving time
- Average driver satisfaction

Performance evaluation (cont.)

Rome (Ave. vehicle speed + Ave. flow rate):

Performance evaluation (cont.)

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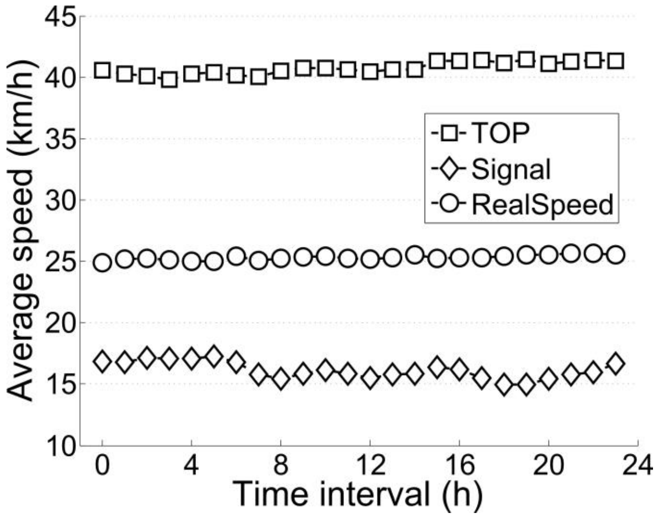

TOP>RealSpeed>Signal

Performance evaluation (cont.)

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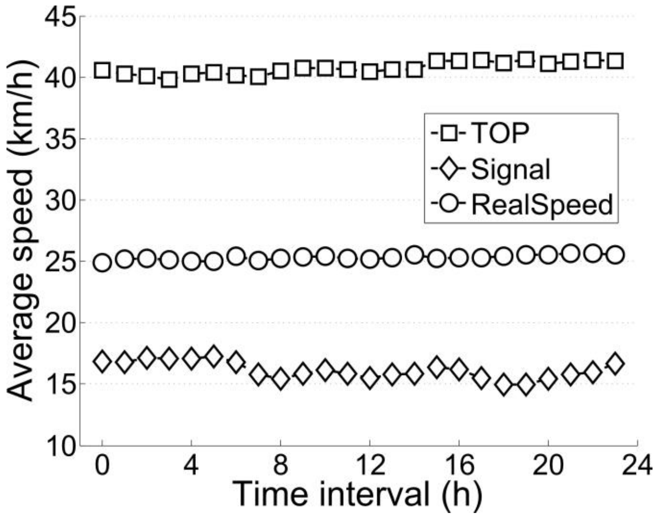

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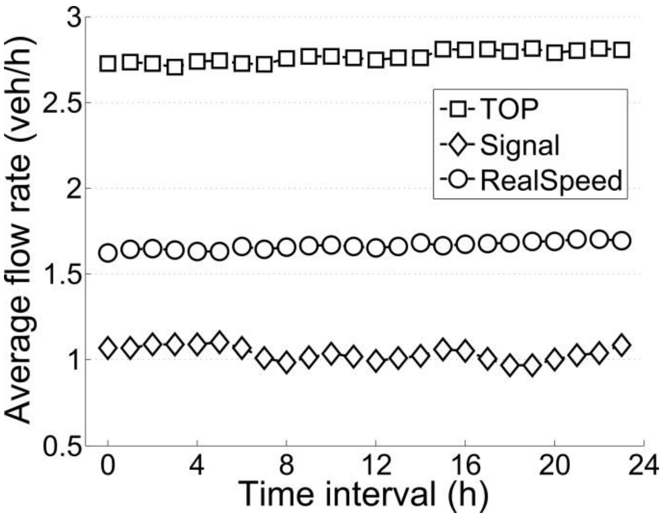

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Performance evaluation (cont.)

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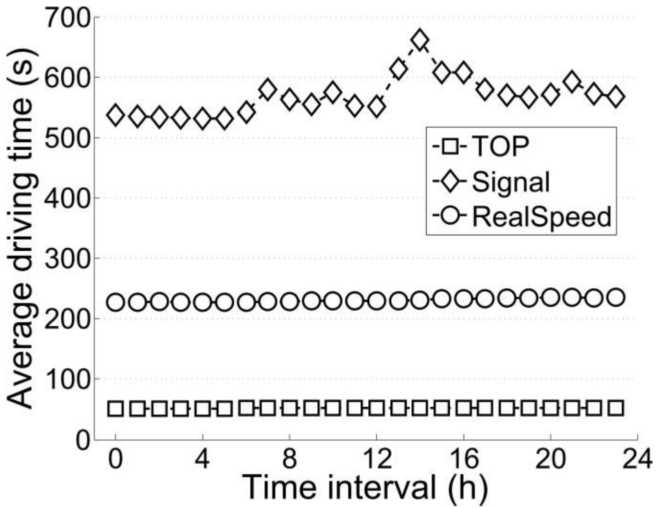

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Performance evaluation (cont.)

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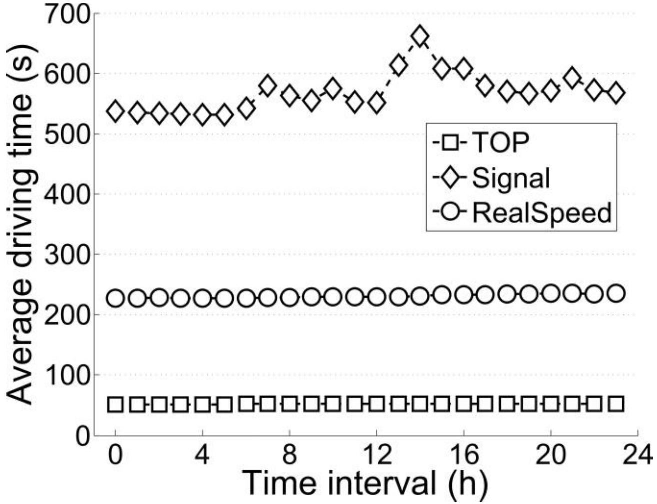

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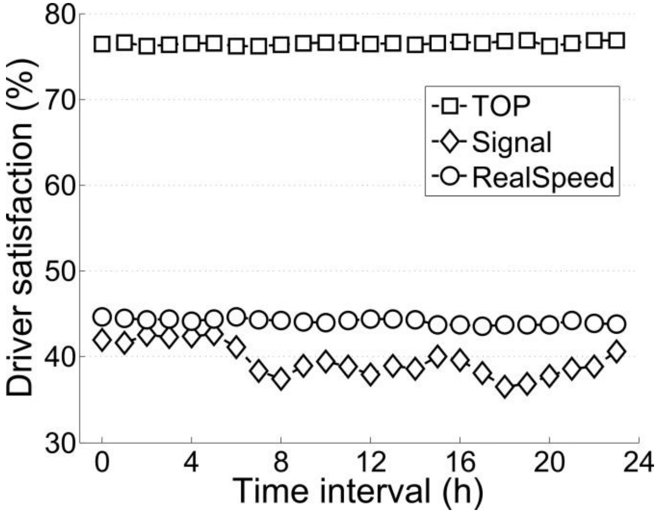

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Conclusions

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2. The formulated non-cooperative Stackelberg game between vehicles and a central server can evenly distribute traffic and avoid congestion.

3. Majority of the vehicles have social patterns, which may be exploited to further avoid the generation of traffic congestion

Thank you!
Questions & Comments?

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University of Virginia