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

Authors: Li Yan and Haiying Shen
Presenter: Ankur Sarker

IEEE MASS
Brasília, Brazil
October 2016
Why is traffic congestion control pivotal?
Why is traffic congestion control pivotal?
Why is traffic congestion control pivotal?
Why is traffic congestion control pivotal?
Use signal to schedule passing of vehicles
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
Problem

Overlook the possible road congestion generation in the future

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

Overlook the possible road congestion generation in the future

http://ops.fhwa.dot.gov/publications/fhwahop09015/cp_prim7_02.htm
TOP: Trajectory based speed OPtimization
**TOP:** Trajectory based speed OPtimization

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
Vehicles' concurrent competition for few popular roads

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
Vehicles' temporal preference on roads

High vehicle density during some times
Vehicles’ temporal preference on roads

Allocate the usage of roads to different time slots

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

1. Current position and intended destination
2. Trajectory and expected vehicle density
3. Speed resulting in maximum utility
4. Final expected vehicle density
5. Final speed corresponding to expected vehicle density
Future vehicle density prediction

Trajectory calculation

For a road segment:

Estimated total travel time:
Future vehicle density prediction

Trajectory calculation

For a road segment:

\[ t_i = \begin{cases} 
\frac{l_i}{v_i^{\text{max}}}, & 0 \leq d_i < d_i^m \\
\frac{l_i}{v_i^{\text{min}}}, & d_i^m \leq d_i < d_i^{\text{jam}} \\
\infty, & d_i \geq d_i^{\text{jam}}
\end{cases} \]

Estimated total travel time:

\[ T_i = \sum_{m=1}^{M_i} t_m \]
Future vehicle density prediction

Trajectory calculation

For a road segment:

\[
t_i = \begin{cases} 
    l_i / v_i^{\text{max}}, & 0 \leq d_i < d_i^m \\
    l_i / v_i^{\text{min}}, & d_i^m \leq d_i < d_i^{\text{jam}} \\
    \infty, & d_i \geq d_i^{\text{jam}} 
\end{cases}
\]

Estimated total travel time:

\[
T_i = \sum_{m=1}^{M_i} t_m
\]

Travel times follow normal distribution, and are i.i.d.
Future vehicle density prediction

Road vehicle density calculation

For a road segment:

\[
d_{i+1}^{s_i} = \sum_{k=1}^{N} P_k (T_i \leq t^e_j - t^s_j)
\]

\(N\) is the number of vehicles that will pass \(s_i\) during \([t^e_j, t^s_j]\)
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:

\[ L(d) = \sum_{i=1}^{N_s} d_i \cdot v_i \]
For central server:

\[ L(d) = \sum_{i=1}^{N_s} d_i \cdot v_i \]

For drivers:

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

\[ \sum_{i} \gamma_i F(v_i, \alpha_i, p_i^j) \]

s.t.  \( v_i \leq v_i^{\text{max}} \)
Driving speed optimization gaming

1. The central server offers densities:

\[ D = \{d_u\} = \ln(u + 1) \cdot \bar{d}_{c+1}, u \in [1, \ldots, n] \]
Driving speed optimization gaming

1. The central server offers densities:

\[ D = \{ d_u \} = \ln(u + 1) \cdot \bar{d}_{c+1}, u \in [1,\ldots,n] \]

2. For each \( d_u \), each vehicle chooses speed by:

\[ \{ v_{ku} \} = \arg \max_{v_k \leq v_k^{\text{max}}} \sum_{k} \gamma_k F(v_k, \alpha_k, p^j_k) \]
Driving speed optimization gaming

1. The central server offers densities:

\[ D = \{ d_u \} = \ln(u + 1) \cdot \bar{d}_{c+1}, u \in [1, \ldots, n] \]

2. For each \( d_u \), each vehicle chooses speed by:

\[ \{ v_{ku} \} = \arg \max_{v_k \leq v_k^{\text{max}}} \sum_k \gamma_k F(v_k, \alpha_k, p_k^j) \]

3. The central server finalizes the expected vehicle density:

\[ d_l = \arg \max_{d_u \in D} L(d_u) = \arg \max_{d_u \in D} d_u \sum_{i} v_{iu} \]
Driving speed optimization gaming

1. The central server offers densities:

\[ D = \{d_u\} = \ln(u + 1) \cdot \bar{d}_{c+1}, u \in [1, \ldots, n] \]

2. For each \( d_u \), each vehicle chooses speed by:

\[ \{v_{ku}\} = \text{arg max}_{v_{k \leq v_{k \max}}} \sum_{k} \gamma_k F(v_k, \alpha_k, p^j_k) \]

3. The central server finalizes the expected vehicle density:

\[ d_l = \text{arg max}_{d_u \in D} L(d_u) = \text{arg max}_{d_u \in D} d_u \sum_{N_S} v_{iu} \]

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

Vehicle mobility traces
Performance evaluation

Vehicle mobility traces

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

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.)

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

TOP > RealSpeed > Signal
Performance evaluation (cont.)

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

TOP > RealSpeed > Signal

TOP > RealSpeed > Signal
Performance evaluation (cont.)

Rome (Ave. driving time + Ave. driver satisfaction):
Performance evaluation (cont.)

Rome (Ave. driving time + Ave. driver satisfaction):

Signal > RealSpeed > TOP
Performance evaluation (cont.)

Rome (Ave. driving time + Ave. driver satisfaction):

Signal > RealSpeed > TOP

TOP > RealSpeed > Signal
Conclusions
Conclusions

1. Vehicle traffic has characteristics that can easily lead to concurrent competition of roads, namely congestion.
Conclusions

1. Vehicle traffic has characteristics that can easily lead to concurrent competition of roads, namely congestion.

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

1. Vehicle traffic has characteristics that can easily lead to concurrent competition of roads, namely congestion.

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?

Li Yan, Ph.D. Candidate

ly4ss@virginia.edu

Pervasive Communication Laboratory

University of Virginia