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第4回 坊ちゃんセミナー

Controlling Connected Autonomous Vehicles for Minimizing Delays at a Bottleneck

Yasuhiro SHIOMI, Ritsumeikan Univ.

Hanshin Expressway　株式会社 地域未来研究所

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Motivations

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- Technological innovation in traffic data collection:
  - Enrichment of realtime traffic data on both Euler and Lagrangian observations enables dynamic traffic state estimation and prediction with high resolution.
- In the era of autonomous and connected vehicles:
  - Innovative idea in traffic operation and control on the basis of V2I communication can be realized.
- Local issues in Japan:
  - Sags are the most common bottleneck on freeways in Japan.

Research questions?

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If we can control specific vehicles in traffic flow exogenously from traffic control center …

- Can we mitigate traffic jam at sag bottleneck?
- If yes, how much it would be?

- Microscopic approach:
  - Representation of sag bottleneck phenomena is still challenging
  - High computational burden
- Macroscopic approach:
  - Parsimony representation of traffic flow
  - Realtime solution for the traffic optimization

State of the art

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- Microscopic approach:
  - ACC, CACC (Schakel et al., 2010): Rule based, and heuristic manner.
  - Model predictive control (Bernat et al., 2016): High computational burden. Difficulties in realtime solution.
- Macroscopic approach:
  - Algorithm of variable speed limit for dissolve shockwaves (Hegyi and Hoogendoorn (2010), Chen et al. (2014)).
    - ➢ Incorporation of "capacity drop" mechanism
    - ➢ Control the speed of all vehicles in the specific time-space domain, which might not be always optimal solution

Objectives

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- To incorporate capacity drop (CD) mechanism into variational theory (VT) of traffic flow
- To investigate the possibility to minimize the delay on sag bottleneck by controlling specific vehicles on the basis of model predictive control (MPC)

Contents

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- Variational Theory (VT)
- Incorporation of capacity drop (CD) into VT
- Representation of CAV's behavior
- Numerical example
  - Settings of VT network
  - Reduction of delay by adjusting arrival timing of autonomous vehicles by applying model predictive control (MPC)
- Conclusions and future works

Variational Theory (VT)

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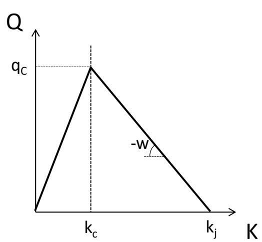
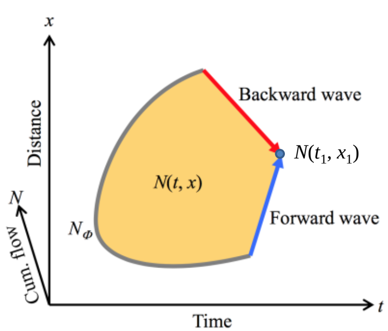
- Proposed by C. Daganzo (2005)



Triangle FD



$$N(t_1, x_1) = \min(N_\Phi, N_\Phi + k_j \Delta x)$$

Incorporation of CD into VT (i)

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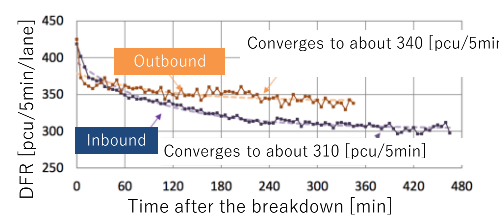
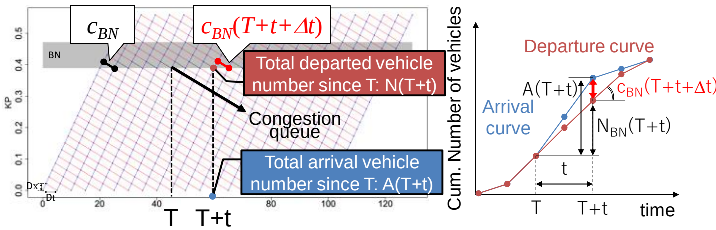
- Koshi et al. (1993): The longer the congestion queue, the lower the discharge flow rate (DFR).
- Chung et al. (2007):When the density becomes higher than a threshold, DFR rapidly decreases.
- Yuan et al. (2015): DFR correlates to the speed in congestion.
- Nagayama et al. (2016): After breakdown, DFR gradually decrease and finally converge on a fixed value.



Incorporation of CD into VT (ii)

- CD is expressed by dynamically discounting the costs of the backward wave links of the bottleneck section.



$$c_{BN}(T+t+\Delta t) = \kappa \cdot \frac{N_{BN}(t)}{A(t)} \cdot c_{BN}$$

Sensitivity Parameter

Incorporation of CD into VT (iii)

- By the formulation of CD, the following evidences can be represented:
  - Koshi et al. (1993): The longer the congestion queue, the lower the discharge flow rate (DFR).
  - Chung et al. (2007):When the density becomes higher than a threshold, DFR rapidly decreases.
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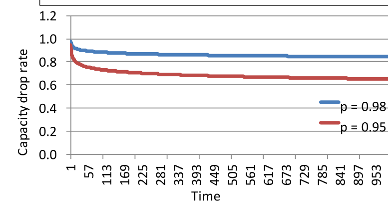

$$p = \frac{\text{Initial Capacity on BN}}{\text{Capacity on upstream section}}$$

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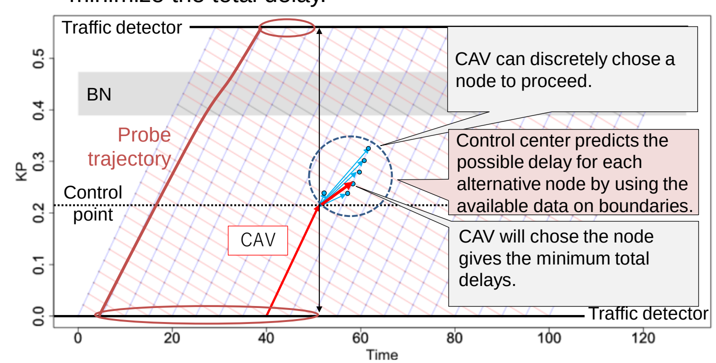
Representation of CAV's behavior in VT

- Assuming that CAVs are exogenously operated by traffic control center, who can know arrival and departure curve on the boundaries and trajectories of some vehicles, to minimize the total delay.



Representation of autonomous vehicle’s behavior in VT

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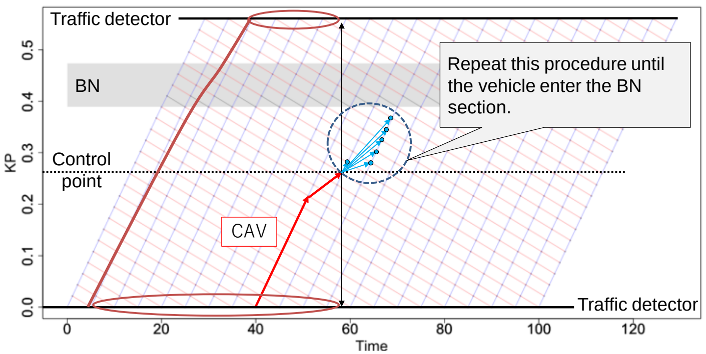
- Assuming that CAVs are exogenously operated by traffic control center, who can know arrival and departure timing of all vehicles and trajectories of some vehicles, to minimize the total delay.



Representation of autonomous vehicle’s behavior in VT

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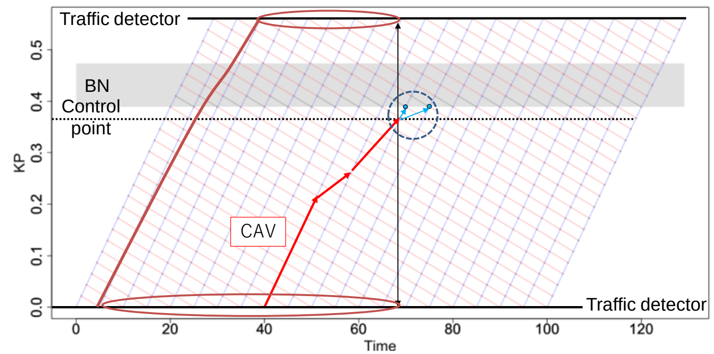
- Assuming that CAVs are exogenously operated by traffic control center, who can know arrival and departure timing of all vehicles and trajectories of some vehicles, to minimize the total delay.



Representation of autonomous vehicle’s behavior in VT

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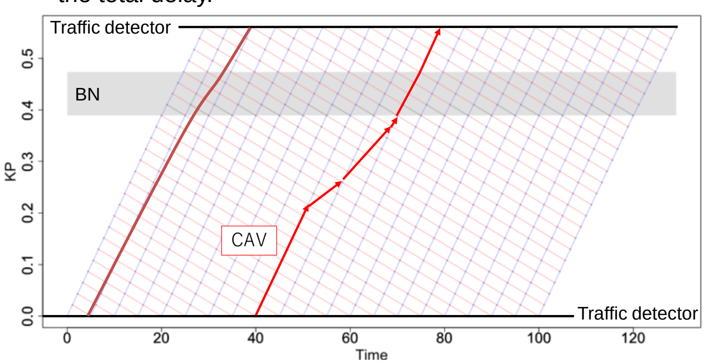
- Assuming that CAVs are exogenously operated by traffic control center, who can know arrival and departure timing of all vehicles and trajectories of some vehicles, to minimize the total delay.



Settings of VT network

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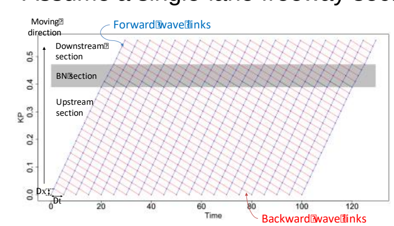
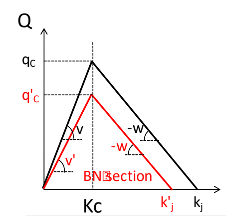
- Assume a single-lane freeway section with a bottleneck.



VT network



Fundamental diagram

Parameter settings of VT network

	v [km/h]	w [km/h]	qc [veh/h]	kc [veh/km]	kj [veh/km]	dt [sec]	dx [m]	L [m]
Upstream	70	-20	3600.0	51.4	231.4		4.32	400
BN	60	-20	3085.7	51.4	205.7	1	4.17	100
Downstream	70	-20	3600.0	51.4	231.4		4.32	100

CD parameter

$$c_{BN}(t+T+\Delta t) = \boxed{\kappa} \cdot \frac{N_{BN}(t)}{A(t)} \cdot c_{BN}$$

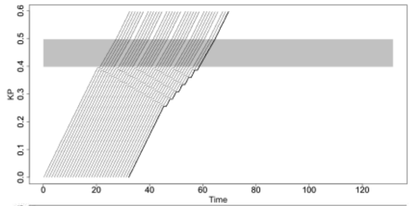
$\kappa = 1.0$

Impact of capacity drop

- Trajectories drawn by VT with or without CD

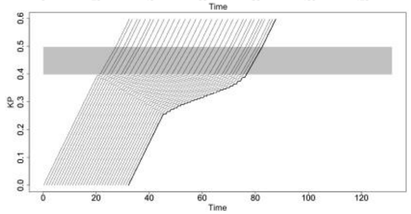
Without CD

Total delay：90.86 sec



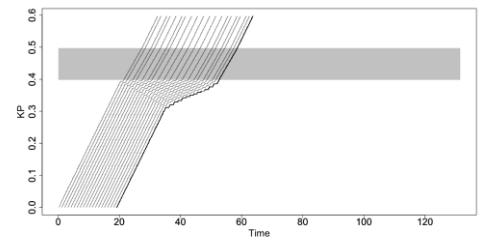
With CD

Total delay：416.67sec



Numerical examples

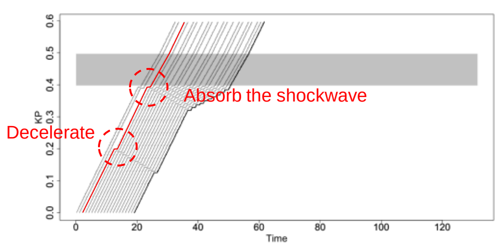
- A platoon with 20 vehicles are coming from the upstream point.
- One of the vehicles is assumed to be autonomous.
  – Relationship between the position of the CAV and the possible delay mitigation is investigated.



With no CAV

Numerical examples

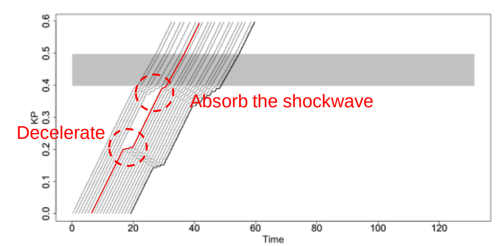
- A platoon with 20 vehicles are coming from the upstream point.
- One of the vehicles is assumed to be autonomous.
  – Relationship between the position of the CAV and the possible delay mitigation is investigated.



The 3rd vehicle is CAV

Numerical examples

- A platoon with 20 vehicles are coming from the upstream point.
- One of the vehicles is assumed to be autonomous.
  – Relationship between the position of the CAV and the possible delay mitigation is investigated.



The 7th vehicle is CAV

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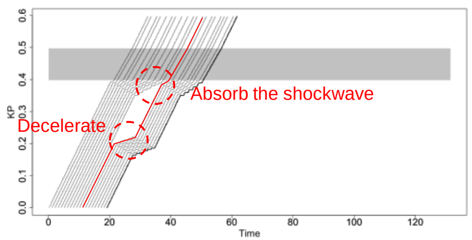
Numerical examples

- A platoon with 20 vehicles are coming from the upstream point.
- One of the vehicles is assumed to be autonomous.
  - Relationship between the position of the autonomous vehicles and the possible delay mitigation is investigated.



The 12th vehicle is autonomous

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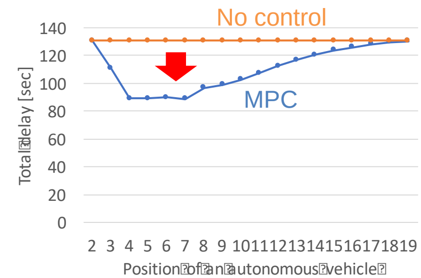
Delay mitigation by MPC

- Depends on the position in the platoon, delay mitigation varied.
- More than 32% of delays are reduced when the autonomous vehicle is on 7th position in a platoon.



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Conclusions

- Incorporate CD into VT
  - Qualitatively represent the characteristics of CD
  - Need quantitative verification on the basis of observed data at sags
- Total delay at bottleneck can be reduced by adjusting the arrival of a CAV
  - MPC works well in accordance with the real time situation
- The amount of delay reduction totally depends on the position of the CAV
  - After the capacity of the bottleneck becomes convergence, this control may not work anymore

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Future works

- Quantitative evaluation of CD
- Integration of traffic state estimation and model predictive control
- Application to merging bottleneck
- Extend to multilane and multiclass, stochastic model …