Mixed Traffic Longitudinal Trajectory Control At Isolated Signalized Intersections

Yu Wang 1; Xiaopeng Li，Associate Professor 1; Handong Yao 2
1 University of South Florida ；2 Harbin Institute of Technology
E-mail: ywang21@mail.usf.edu ; xiaopengli@usf.edu

CONTRIBUTIONS

- A new concept of **spatially and temporally heterogeneous** IVSL design is proposed; i.e., a vehicle may adopt different speed limits at different portions of a road segment at different times;
- Mixed traffic, i.e., CAVs and HVs, is considered in mixed traffic longitudinal trajectory control to achieve the optimal system performance for the whole vehicle platoon.

INTRODUCTION

Traffic signals on urban highways force vehicles to stop frequently and accelerate/decelerate abruptly, and thus causes excessive travel delay, extra fuel consumption and emissions, and increased safety hazards.

This paper proposes a Longitudinal Trajectory Control (LTC) method with pre-fixed traffic signals. This method dynamically imposes speed limits on some identified Target Controlled Vehicles (TCVs) with Vehicle to Infrastructures (V2I) communication ability at two VSLs along an approaching lane. Essentially, only TCVs' trajectories need to be controlled and the other vehicles just follow TCVs with Gipps' car-following model. In addition, queueing effect of HVs and CAVs' market penetration rate are considered in mixed traffic situations.

METHODOLOGY

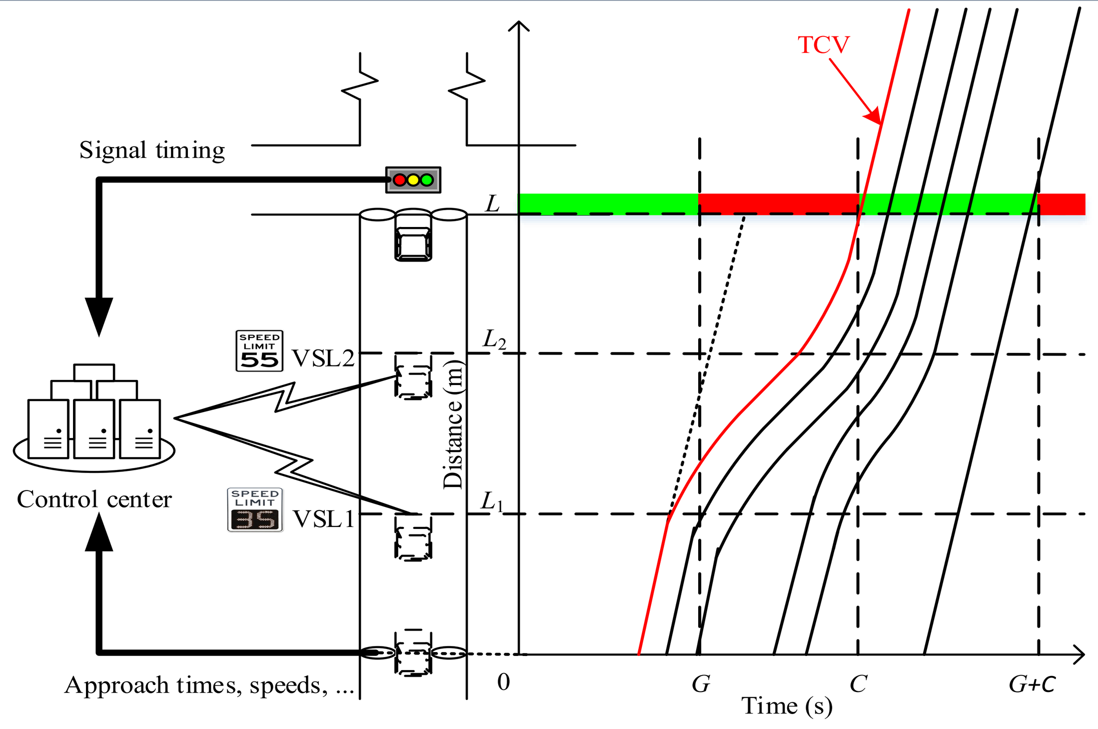

Fig. 1 Framework of VSL-LC system

Traffic dynamics:

- For TCV (specified lead CAV in platoon):

$$\dot{x}_n(t+\Delta t)=\begin{cases}\min\left\{F^{Gipp}\left(\dot{x}_n(t),\dot{x}_{n-1}(t),s_n(t)\right),\max\{\overline{v}_n,\dot{x}_n(t)+d\times\Delta t\}\right\}, & \text{if } x_n(t)\in[L_1,L_2];\\ F^{Gipp}\left(\dot{x}_n(t),\dot{x}_{n-1}(t),s_n(t)\right), & \text{otherwise}\end{cases}$$

- For non-TCV (HVs and part CAVs):

$$\dot{x}_n(t+\Delta t)=\begin{cases}\min\{F^{Gipp}\left(\dot{x}_n(t),\dot{x}_{n-1}(t),s_n(t)\right),F^{Gipp}\left(\dot{x}_n(t),0,L-x_n(t)\right)\}, & \text{if } t\le(i_n+1)C;\\ F^{Gipp}\left(\dot{x}_n(t),\dot{x}_{n-1}(t),s_n(t)\right), & \text{otherwise.}\end{cases}$$

Location Optimization:

Joint objectives (M) Travel time (TT) and Fuel Consumption (FC):

$$\min_{L_1,L_2} M(\boldsymbol{L_1},\boldsymbol{L_2})=\omega_T TT(\boldsymbol{L_1},\boldsymbol{L_2})+\omega_F FC(\boldsymbol{L_1},\boldsymbol{L_2})$$

s.t.

$L-\frac{v_{max}{}^2}{2a}\le L_2\le L.$ Confines an effective range.

$0\le L_1\le L_2-\frac{v_{max}{}^2}{2d}.$ Ensure spacing for deceleration.

and $\mathbf{x}=\{x_n\}_{n\in N}.$ Subject to control measure.

Solution:

DIRECT method (Jones, Perttunen et al. 1993) is applied to numerically search for the optimal solution

NUMERICAL TESTS

Test 1 - Solution Performance

- Objective shape is not unimodal.
- But the variation is bounded continuous.

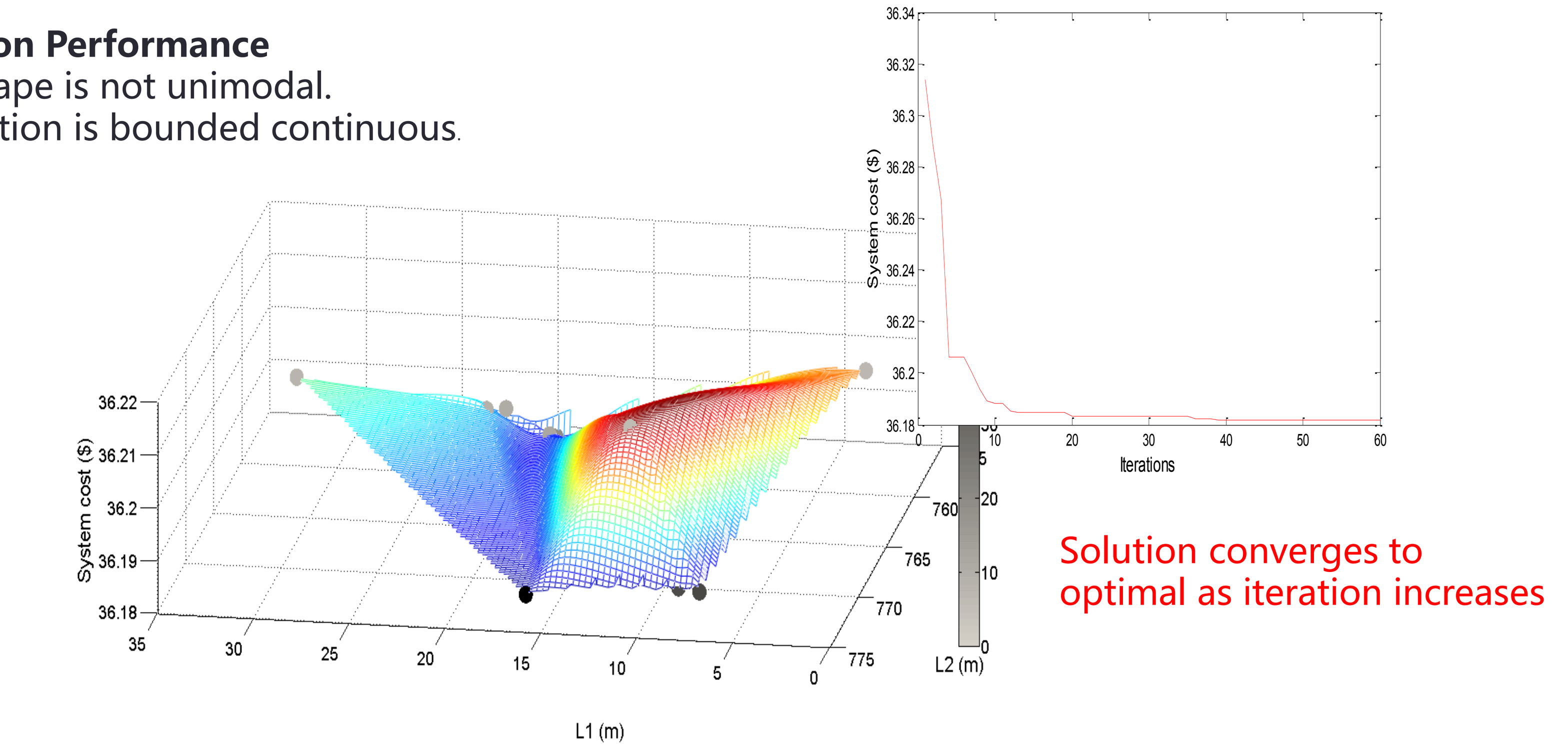

Fig. 2 Objective M(L1,L2) vs. locations L1 and L2 and convergence of the DIRECT solution

Test 2 - System Performance

$Volume/Capacity$	**0.32**	**0.68**	**0.84**	**1.0**	**1.2**
TT^B**(min)**	75.55	93.20	114.47	121.25	124.93
FC^B**(liter)**	8.30	10.33	12.30	12.76	13.08
M^B**($)**	33.49	41.40	50.46	53.18	54.72
TT^A**(min)**	73.18	85.47	NAN	NAN	NAN
FC^A**(liter)**	7.00	7.94	NAN	NAN	NAN
M^A**($)**	31.40	36.42	NAN	NAN	NAN
TT^***(min)**	72.52	84.48	106.02	113.03	116.88
FC^***(liter)**	7.06	8.04	9.12	9.68	10.93
M^***($)**	31.23	36.18	44.46	47.36	49.89
L_1^M	0.72	12.06	231.13	374.94	504.55
L_2^M	759.57	758.26	762.82	761.77	769.84
ΔTT^A	0.9%	1.2%	NAN	NAN	NAN
ΔFC^A	-0.8%	-1.3%	NAN	NAN	NAN
ΔM^A	0.5%	0.6%	NAN	NAN	NAN
ΔTT^*	4.0%	9.4%	7.4%	6.8%	6.4%
ΔFC^*	15.0%	22.2%	25.9%	24.2%	16.4%
ΔM^*	6.7%	12.6%	11.9%	11.0%	8.8%

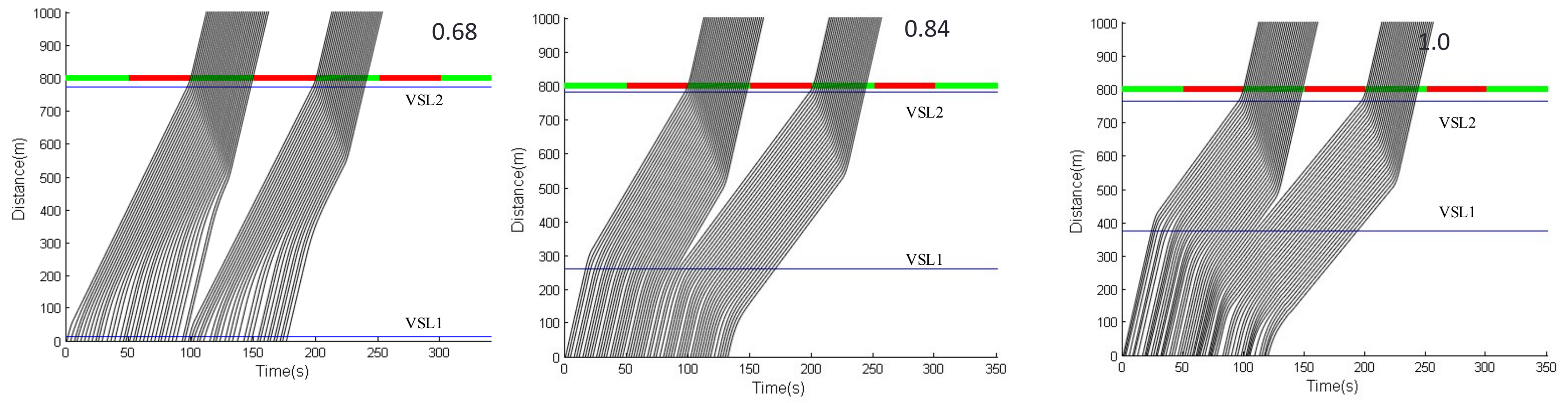

Fig. 3 Trajectories respect to different traffic levels.

ASL may cause excessive queue spillback under dense traffic conditions. LTC can circumvent this disadvantage by optimally setting the speed slow down point according to traffic volume.

Test 3 – Market Penetration Rate Analysis

Improvements drop with the market penetration rate decreases, especially under 5%. And compared to ASL, LTC is more robust.

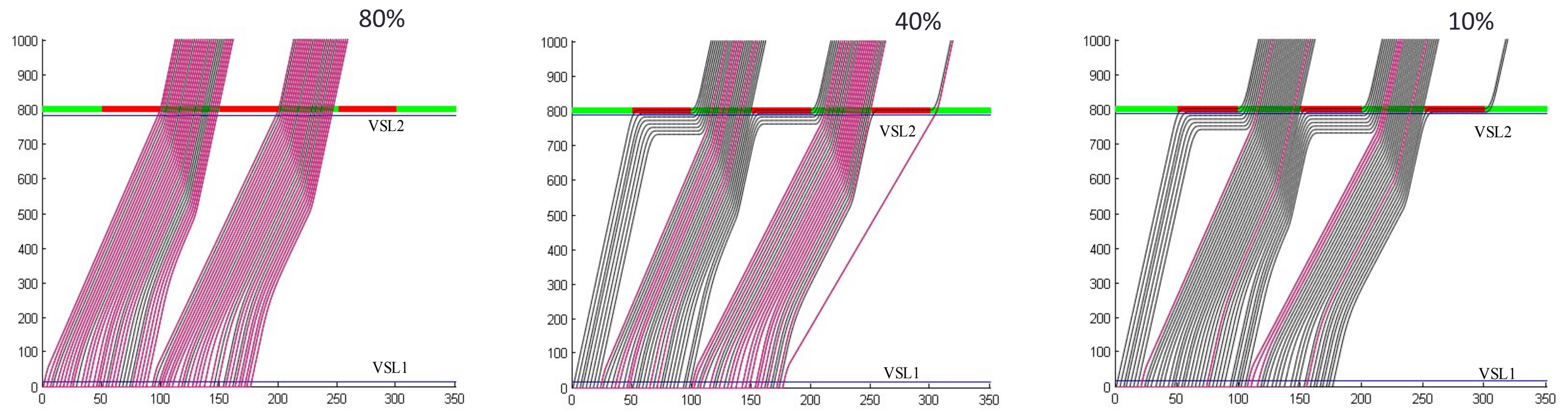

Fig. 4 Trajectories respect to different market penetration rates.

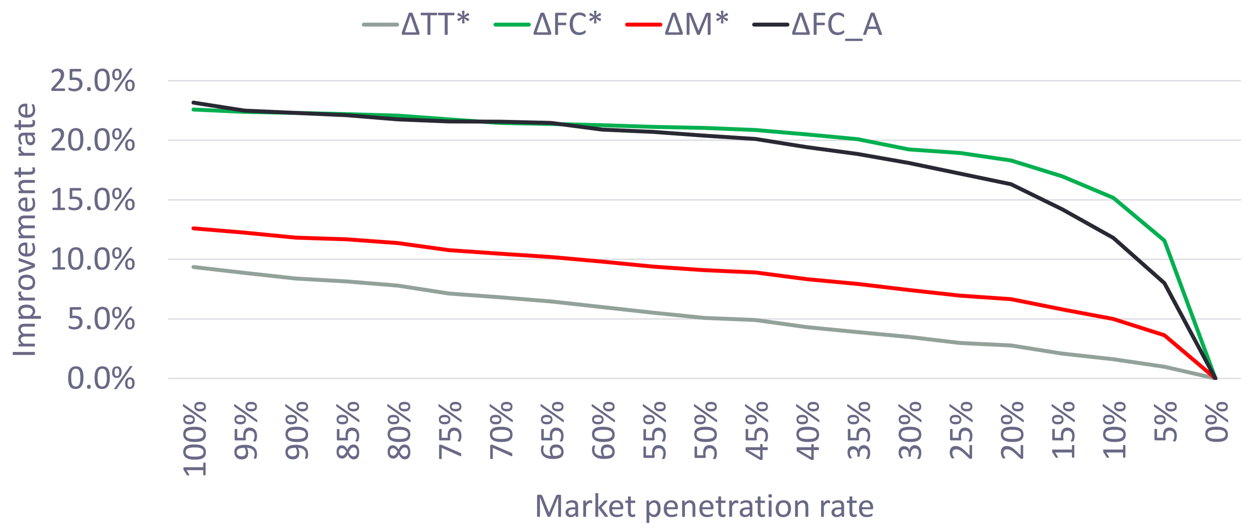

Fig. 5 The improvement with market penetration rate for different objectives.

CONCLUSIONS

- This paper proposes a novel vehicle longitudinal trajectory control method (i.e. LTC) with spatially and temporally heterogeneous design.
- DIRECT can find the global optimal solution due to the bounded continuous of objective function.
- LTC optimally balances trajectory smoothing and queue storage at different Volume/Capacity ratios under different traffic demands.
- Market penetration rate does affect the effectiveness of LTC, and LTC performs more robust than ASL at a low market penetration rate.