A joint trajectory and signal optimization model for connected automated vehicles at signalized intersections and work zones

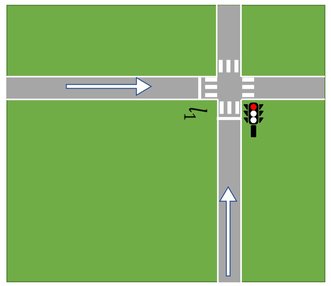
Amir Ghiasi [a], Xiaopeng Li [a], Xiaobo Qu [b]
a. Department of Civil and Environmental Engineering, University of South Florida, Tampa, U.S.
b. Department of Civil and Environmental Engineering, University of Technology Sydney, Sydney, Australia

Introduction

- Stop-and-go traffic at intersections and work zones impose significant delay and environmental impacts
- With connected autonomous vehicles (CAVs), we are able to control traffic to reduce traffic delay and fuel consumption

Literature Review

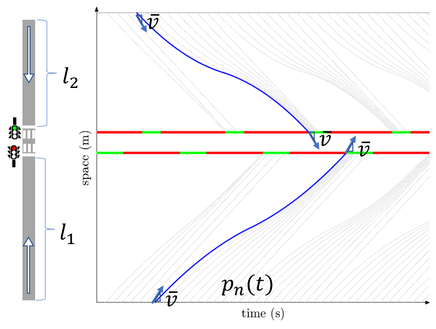
- CAV trajectory optimizations, e.g., Zhou et al., 2017; Ma et al., 2017
- Signal timing design for CAVs, e.g., Li et al., 2014; Guler et al., 2014; Zheng and Liu, 2017
- Few macroscopic joint optimization of CAV trajectory and signal timing in the literature

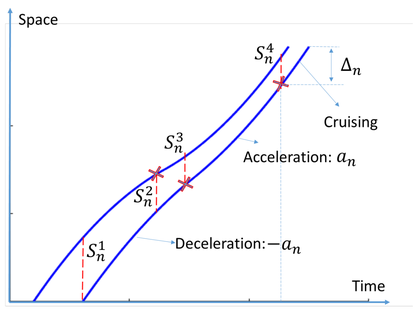


Objectives

- An exact optimization model to determine
  - CAV trajectories; and Signal timing plan
  - Minimize traffic delay and fuel consumption
- Applicable to signalized intersection and work zones

Trajectory and Signal Planning





Safety constraint

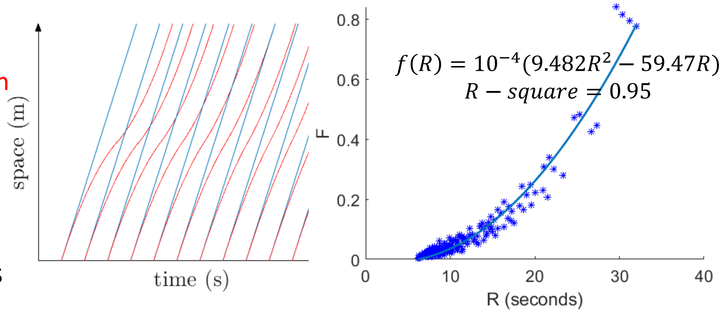
$$S_n^k(t) = p_{n-1}(t) - p_n(t) - \left(s_0 + v_n(t)\tau^R + \left(v_n(t) - v_{n-1}(t)\right)\tau^{TTC}\right) \geq 0$$
$$\Longrightarrow \Delta_n^{\min}$$

$$\min_{R_1,R_2} Z := \frac{1}{C}\sum_i \underbrace{(D_i(R_i)}_{\text{Delay}} + \underbrace{wF_i(R_i,\{p_n\})}_{\text{Fuel consumption}}$$

$$\approx \frac{1}{C}\sum_i \left(D_i(R_i) + wf(R_i)\right) \Rightarrow R_1^*(C)$$

s.t.: $S_n^k(t) \geq 0, \forall k = 1, \dots, 4$
and boundary and kinematic constraints

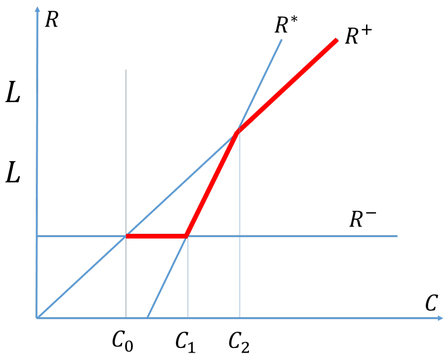
Marginal fuel consumption

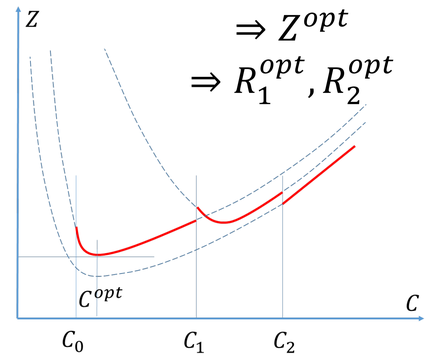


Analytical solution

$$R_1^- = \frac{\mu_2(\mu_1 - \lambda_1)}{\mu_1\mu_2 - \lambda_1\mu_2 - \lambda_2\mu_1}L$$
$$R_2^- = \frac{\mu_1(\mu_2 - \lambda_2)}{\mu_1\mu_2 - \lambda_1\mu_2 - \lambda_2\mu_1}L$$
$$R_1^+ = C + L - R_2^-$$

μ_i: saturation flow rate
λ_i: arrival rate L: lost time

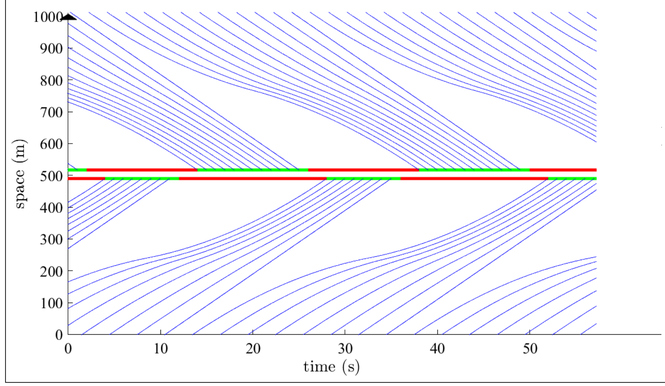




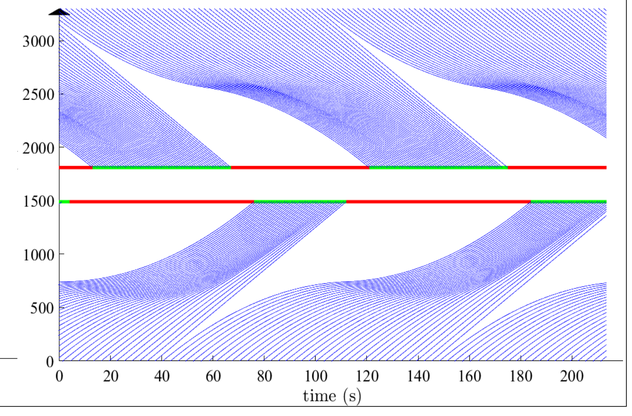
Numerical Experiments

$\lambda_1 = 1200, \lambda_2 = 1800$ vph	$\mu_1 = \mu_2 = 3600$ vph	$\bar{v} = 20$ m/s	$w = 40$	$\tau^R = 0.5$ s	$\tau^{TTC} = 1.0$ s
$L^{inters.} = 4$ s (intersection length: 7 m)	$L^{work} = 18$ s (work zone length: 300 m)	$l^{inters.} = 500$ m	$l^{work} = 1500$ m	$s_0 = 10$ m	

Intersection



Work zone



Conclusions and Future Approach

Conclusion

- A joint optimization of traffic delay and fuel consumption
- The complex function of fuel consumption can be replaced with a simple function of the red interval
- This model is applicable to signalized intersection and work zones

Future research direction

- Traffic dynamics and stochasticity
- Oversaturated traffic

Acknowledgements

This research is partially supported by the U.S. National Science Foundation (NSF) through Grant CMMI#1453949

For more info, contact:
xiaopengli@usf.edu
amirghiasi@mail.usf.edu
(813) 974-0778