Smart Urban Signal Infrastructure and Control

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Objectives

(a) to investigate the transition and impact of traffic signal systems
(b) to develop robust signal control schemes leveraging connected and automated vehicle technologies.

Work scope:

- This study for FY18 describes the development of several new multi-input and multi-output (MIMO) traffic signal control method that can improve network-wide traffic operations in terms of reduced travel delay and energy consumption.
- A 35-intersection network of Bellevue, WA is used as the basis for the development of the algorithm for travel delay reduction control.
- The proposed control method is evaluated in a microscopic traffic simulation environment, VISSIM. Simulation results show that the proposed methods has led to 40% - 55.7% travel delay reduction when compared with the delays of conventional pretimed and actuated controls.

Traffic Data and Simulation Model

- A grid road network from downtown Bellevue (WA) has been selected as the networked intersections area of this study.
- The study area covers from Main Street (the south) to NE 12th Street (the north) and from Bellevue Way NE (the west) to 112th Ave NE (the east).
- It includes 35 intersections and 57 major bi-directional road links, with average link length being 664.4 ft (see Fig. 1-a).
- Traffic count data by movements were collected for each intersection in the midday off-peak period (i.e., 1-2 pm) (see Fig. 1-b).
- Vissim simulation model developed by the City of Bellevue (calibrated using actual traffic data) was used in this study (see Fig. 2).

Fig. 1 (a) Traffic count data (left) and (b) road network and traffic volume (right).

Fig. 2 (a) Vissim simulation model; and (b) intersection layout of a specific intersection.

System Modeling

- Given a fixed cycle length, say 90s, we denote the north-south direction green time of intersection i as u_i ,where $u_i \in [0, 80s]$ and $i = 1,2,\dots,35$.
- For each intersection, we have two delay measurements, i.e., the delay in the north-south (N-S) direction and the delay in the east-west (E-W) direction. In other words, there is a total of 70 delay measurements for the 35 intersections.
- For intersection i, the N-S direction delay is denoted by y_{2i-1} and the E-W direction delay is denoted by y_{2i} ,where $i = 1,2,\dots,35$.
- In this context, the traffic network can be represented by the discrete time input-output dynamic model:

$$y(k) = F(y(k-1), v(k-1), w(k)) + noise \quad (1)$$

where $y \in R^{70}$ is the traffic delay of E-W and N-S direction at each node, $v \in R^{35}$ is the system control input, representing in particular the green signal period of N-S direction of each node, and k indicates the time steps (step size = 90s). F stands for the nonlinear relationship between the delays and the green signal period.

__Various Models:__ Assuming the nonlinearity of the traffic network is linearizable, one can simplify the above system with the following model for $v \in [u_{min}, u_{max}]$:

TYPE I: $\Delta y(k) = H\Delta v(k) + w(k)$ (2a)

TYPE II: $\Delta y(k+1) = A\Delta y(k) + B\Delta v(k) + w(k)$ (2b)

TYPE III: $\Delta y(k+1) = f(\Delta y(k)) + B\Delta v(k) + w(k)$ (2c)

where $H \in R^{70\times 35}$ is the system matrix, Δy and Δu are the increments of y and u at linearized point u^* ,respectively.

Real-time MIMO Feedback Control

- The control objective is to design a controller for the simplified traffic system (2) to achieve tracking of an __optimized travel delay time, $y^* = 0$__ .
- To achieve this control objective, we need to select the green signal period u(k) to achieve the following:

$$\Delta y(k) = -\Gamma(y - y^*) \quad (3)$$

where Γ > 0 is the controller parameter to be specified by user.

- __TYPE I Control__: Assuming the rank of matrix H equals to the number of its columns (i.e., high H-matrix), expected controller structure can be obtained:

$$v(k+1) = u(k) + \Delta v(k) \quad (4)$$
$$\Delta v(k) = -(H^T H)^{-1} H\Gamma(y(k) - y^*) \quad (5)$$

where $u(k) \in [u_{min}, u_{max}]$ is the required constraints.

- __TYPE II Control:__ Using the dynamic linear model, the Adaptive Linear Quadratic Control can be obtained to give

$$\Delta v(k) = argmin\{\textstyle\sum_1^{t_f}(\Delta y^T(k) Q \Delta y(k) + \Delta v^T(k) R \Delta v(k)\} \quad (6)$$

where Q and R are positive definite weighting matrices and the above control law is obtained using adaptive Riccati equations. It still leads to a state feedback rule as in equation (5)

- __TYPE III Control:__ The bilinear control aims at minimizing the travel delay again with the following control strategy

$$v^*(k+1) = \arg \min_{v(k+1)} \max [y(k+1)]$$
$$\text{s.t.} \quad v_{min} \le v(k+1) \le v_{max}$$

$$y(k+1) = Ay(k) + B[v(k+1) - v(k)] + [C(v(k+1) - v(k))] \odot y(k).$$

Results

- We tested the proposed linear control algorithm with different initial N-S green times and compared its performance with the corresponding pretimed control (i.e., the green time = the initial green time and remains unchanged during the whole simulation).
- When compared with corresponding pretimed controls, the proposed linear control given in (5) results in shorter average vehicle delays.
- Figure 4 shows the results of all the three MIMO stochastic control effects, they show significant travel delay reduction per compared to the existing methods.

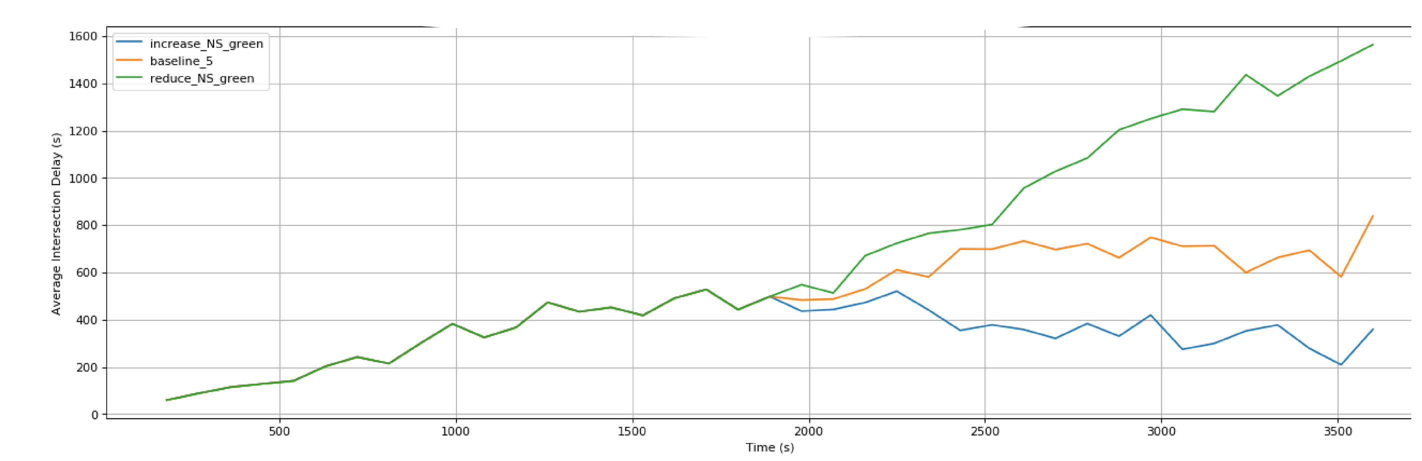

Fig. 3 Delay of the N-S approach of the intersection 1 with different control strategies.

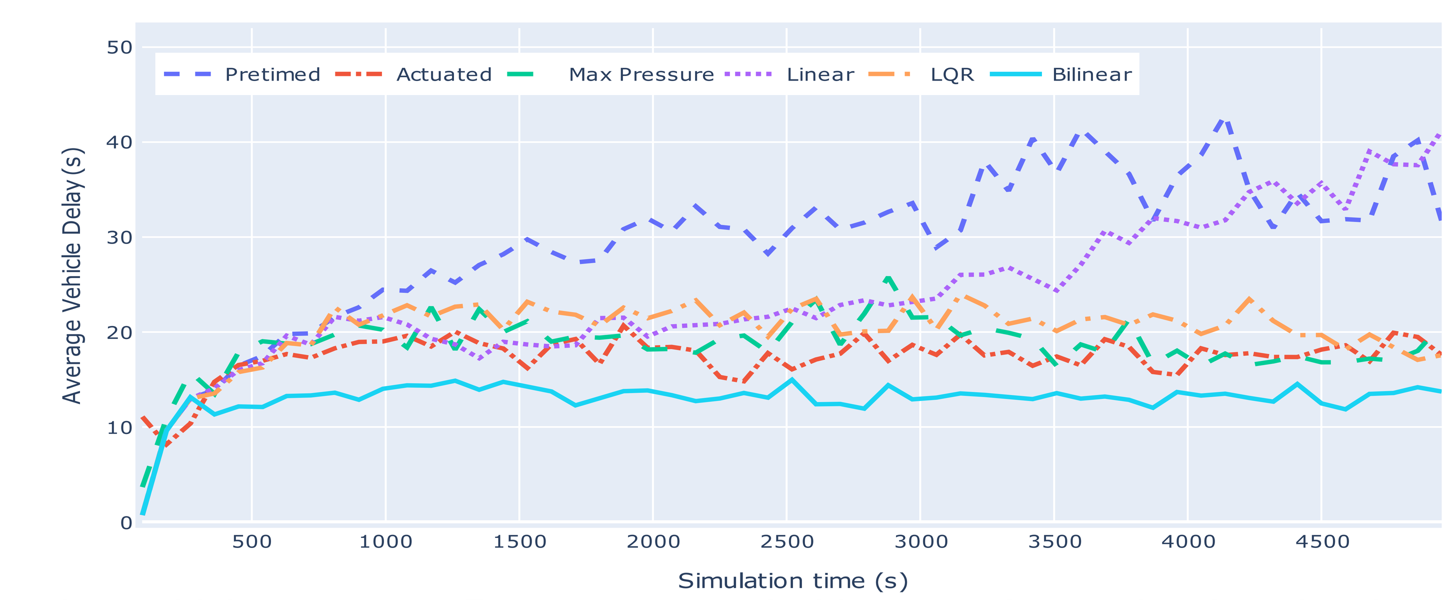

Fig. 4 Initial green = 40s, Γ = 0.2, compared with actuated control and pretimed control.

Summary and Future Work

- Three dynamic traffic system models are built to reflect how each intersection's signal control input will affect network-wide vehicle delay measurement.
- Based on the system models, corresponding MIMO control methods are proposed for network-wide traffic signal control.
- Results show that the proposed methods outperforms corresponding pretimed control, max-pressure and even actuated control with proper initial green time.
- For future research, dynamic and stochastic control methods will be explored to improve the results integrating adaptive routing.

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Reference,

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