Traffic Signal Control With Connected Vehicles

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INTRODUCTION

Most traffic-signal timing plans are designed to minimize vehicles' lost time, based on volumes seen in the past, not the present. In-pavement loop detectors and video detection sometimes are used to make small adjustments to the timing plan, but are too inaccurate, expensive and limited in physical range too provide the level of detection needed to adapt to traffic in real time.

However, an emerging technology, known as connected vehicles, combines several advances – such as wireless communications, on-board computer processing, advanced vehicle sensors, GPS and smart infrastructure – to provide a networked environment. In a connected-vehicle environment, vehicles anywhere within 300 meters of an intersection could communicate continuously with a traffic signal through a dedicated wireless channel. The traffic-control logic developed here uses this new data, i.e., precise vehicle locations, headings and speeds, to minimize vehicle delay and adapt instantly to changing conditions.

Results from simulation show the algorithm maintains or improves performance, compared to a state-of-the-practice, coordinated-actuated timing plan optimized by Synchro at low- and mid-level volumes, but performance worsens during saturated and oversaturated conditions. Testing also showed improved performance during periods of unexpected high demand and the ability to automatically respond to year-to-year growth without retiming.

BACKGROUND

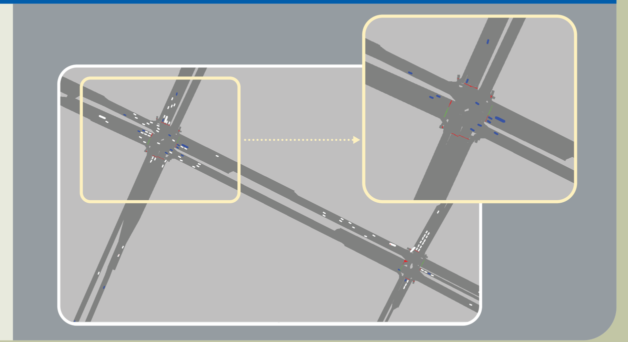
Traffic-signal control is limited by its detection technology and, as a result, is often programmed to serve traffic patterns similar to those experienced in the past. Wireless communication between vehicles and infrastructure systems – often referred to as connected vehicles – provides more robust and complete data on vehicle positions and speeds and allows for more dynamic signal control.

Predictive Microscopic Simulation Algorithm

The traffic-control strategy presented here is the predictive microscopic simulation algorithm (PMSA), named because it predicts the locations of vehicles a short time into the future using microscopic simulation based on possible signal phasings and current vehicle trajectories. It is a decentralized strategy that uses the "rolling horizon" strategy, where the signal's objective is to minimize delay over the next 15 seconds.

STEP 1

Use the speed, heading and location of all equipped vehicles to populate a microscopic simulation model of the intersection.

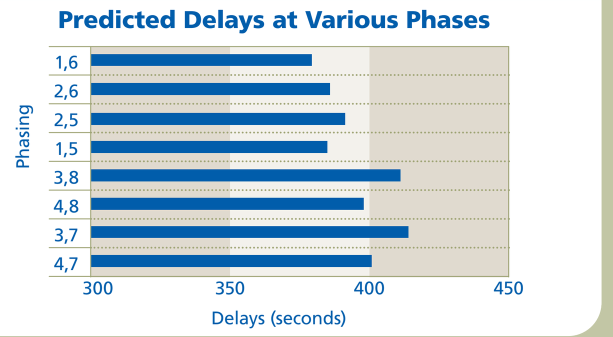


STEP 2

Simulate vehicle positions 15 seconds into the future, including the necessary yellow and red time for a signal change.

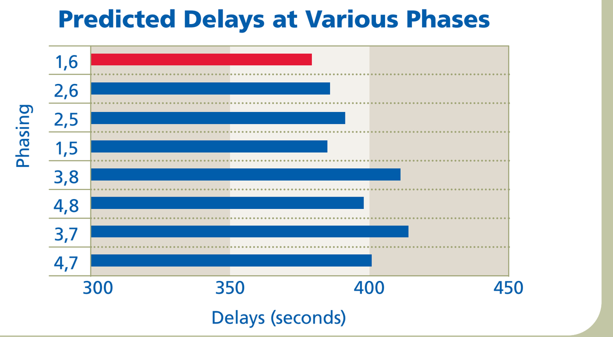
STEP 3

Repeat the simulation for every potential possible phase that the current signal timing plan allows, including the current phase.



STEP 4

Select the phase with the lowest predicted cumulative delay as the next phase. Each phase has a maximum red time of 120 seconds, and disruptive queues trigger an immediate green.



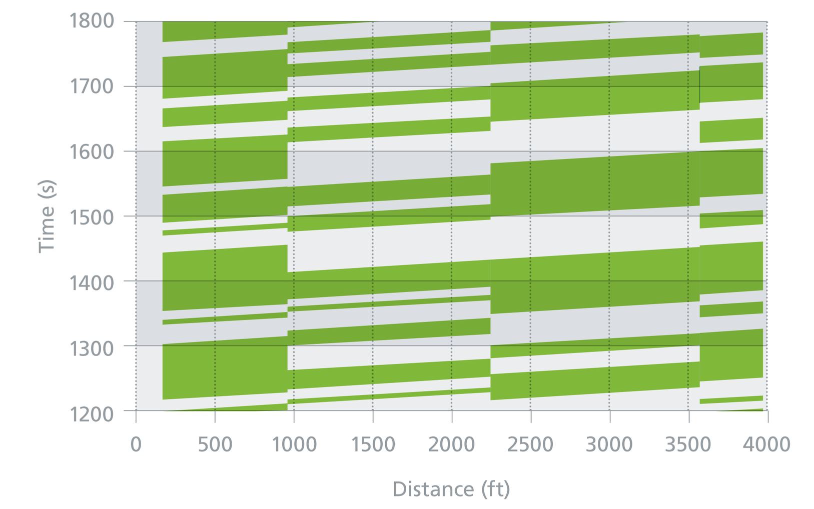
Evaluation Results

Performance of PMSA at Various Equipped-Vehicle Penetration Rates

Equipped-Vehicle Penetration Rate	Method	Delay (s/veh)	Average Speed (mi/hr)	Stopped Delay (s/veh)	Stops
—	Coordinated Actuated	54.20	27.98	30.90	6807
10%	PMSA	66.11*	26.01*	34.79*	11431*
25%	PMSA	58.09*	27.32*	27.15*	10233*
50%	PMSA	52.26*	28.35*	22.98*	9254*
100%	PMSA	51.06*	28.61*	25.46*	7417*

*n = 10, p < 0.05

Eastbound Signal-System Coordination of the PMSA Under Decentralized Control



Performance of PMSA at Various Saturation Rates (Demands)

Saturation Rate**	Method	Delay (s/veh)	Average Speed (mi/hr)	Stopped Delay (s/veh)	Stops
0.45	Coordinated-Actuated	41.79	30.51	24.49	2818
	PMSA	39.95	30.72	24.41	2612*
0.60	Coordinated-Actuated	51.75	28.62	30.63	4868
	PMSA	50.22	28.72	29.89	4825
0.75	Coordinated-Actuated	54.20	27.98	30.90	6807
	PMSA	51.06*	28.61*	25.46*	7417*
0.90	Coordinated-Actuated	69.81	25.61	41.03	12640
	PMSA	77.87*	24.32*	40.13	19102*

*n = 10, p < 0.05 **Approximate average saturation rate based on Synchro's ICU metric

Results from Unexpected Conditions

The PMSA performs best at participation rates of greater than 25 percent and during under-saturated conditions, when compared to a correctly timed coordinated actuated timing plan. The greatest strengths of the algorithm, however, are experienced when traffic demands are greater than anticipated.

Performance of PMSA During an Unexpected 30% Increase in One-Way Volumes on the Mainline

Method	Delay (s/veh)	Average Speed (mi/hr)	Stopped Delay (s/veh)	Stops
Coordinated-Actuated	78.47	24.42	39.61	14260
PMSA	58.33*	27.54*	28.76*	9233*
Percent Change	-25.6%	12.8%	-27.4%	-35.3%

*n = 10, p < 0.05

Performance of PMSA on a Network with 3% Annual Volume Growth Against a 10-Year-Old Coordinated-Actuated Timing Plan

Method	Delay (s/veh)	Average Speed (mi/hr)	Stopped Delay (s/veh)	Stops
Coordinated-Actuated	69.85	25.50	39.86	9486
PMSA	51.06*	28.61*	25.46*	7417*
Percent Change	-26.9%	12.2%	-36.1%	-21.8%

*n = 10, p < 0.05

Conclusions

The PMSA, by using predicted vehicle movements based on their current trajectories, has the potential to outperform coordinated-actuated systems during under-saturated conditions as well as during unexpected conditions. Although the algorithm has several limitations, specifically during saturated flow and at low equipped-vehicle penetration rates, it has several advantages over traditional control – e.g., no tracking of vehicles, no memory of individual or aggregated vehicle movements, minimal timing plan maintenance, and adaptability to unexpected demands.

Acknowledgements

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