Get More Out of Variable Speed Limit (VSL) Control: An Integrated Approach to Manage Traffic Corridors with Multiple Bottlenecks

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Project Objective

Traffic congestion and the resulting stop-and-go motion of traffic on freeways increases travel delay, consumes more fuel and poses greater crash risks to motorists. Variable speed limit (VSL) control, where motorists are advised to travel under a lower speed limit on certain sections of the road, has been used to smooth traffic flow and reduce congestion. This project develops VSL control strategies to reduce fuel consumption and emissions on a freeway with multiple bottlenecks. The core objective is to minimize fuel use and emissions with no or minimal increase of travel time.

Problem Statement

Research has shown that VSL can increase the throughput of a highway bottleneck or reduce fuel consumption when traffic is not congested, but these findings were obtained under the situation where there is only a single bottleneck in the controlled section. In reality, a freeway often has multiple bottlenecks and congestion from downstream bottlenecks can grow to affect upstream ones. In this project, we develop VSL control strategies that take into account the interactions between bottlenecks and the characteristics of traffic flow as revealed by the so-called fundamental diagrams.

Research Methodology

We first identify the optimal range of speed for fuel efficiency, then applies control theory to develop two variable speed limit control strategies to maintain traffic speed in this optimal range while considering traffic flow dynamics:

1. Flow-based FC-VSL. This control strategy aims at saving fuel while maximizing vehicle throughput and preventing congestion to occur at any bottleneck.
2. Density-based FC-VSL. The control strategy aims at maintaining the density of freeway segments around the target density (which is determined by the fuel-efficient speed) by adjusting the speed limits of adjacent segments.

As a comparison, static speed limit control, where the fuel efficient speed is used as the speed limit, is also adopted.

The three VSL control strategies are then evaluated using the microscopic traffic simulator, SUMO, on a stretch of Interstate 80 near Davis, California. This stretch of I-80 is 10 miles long, has 6 junctions across the city of Davis, with three known bottlenecks in the east bound direction. In the simulation, the freeway section is divided into 19 VSL control segments, where each segment can have its own speed limit. The top speed limit for this freeway is set to 75 mph in the simulation, and the fuel efficient speed was found to range from 35 mph to 50 mph based on SUMO's fuel consumption model. Four fuel efficient speeds, 35, 40, 45, and 50mph are used in the evaluation.

Results

1. The density-based FC-VSL reduces fuel consumption and CO2 emissions by over 10% in each case, which is significantly better than the other two VSL strategies.
2. All of the VSL controls increased the average travel time over the baseline (no VSL control). The higher the target speed, the lower this increase. Since the fuel consumption or CO2 emissions does not change substantially from 35 mph to 50 mph in the SUMO model, it is more desirable to choose a higher fuel efficient speed in the control. When we choose 50mph as the target speed, fuel consumption is reduced by 14% while average travel time is creased by 1min/10mi, which translates into a 9% increase.
3. Flow-based VSL performed even worse than static speed limits. The reason for this is that it transfers congestion to upstream, such that the improvement in the controlled downstream sections was outweighed by the degradation in the upstream sections. This highlights the need for taking into account the spillover effects of traffic controls in their performance evaluations.