Reducing Truck Emissions and Improving Truck Fuel Economy via ITS Technologies

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Project Objective

Congestion is detrimental to traffic mobility, safety and the environment, especially for road segments with high truck volume. To relieve congestion, reducing truck emissions and improving truck fuel economy, different Intelligent Transportation System (ITS) techniques, e.g. variable speed limit (VSL), ramp metering (RM), and lane change control (LC) etc., are widely researched. However, the impact of these control approaches to traffic mobility and environment has been controversial in microscopic simulations and field tests. The aim of this project is to use analysis and control theory to research the cause of these inconsistencies and develop feedback traffic flow controllers that provide consistent improvements in mobility, environmental impact and safety. Special attention will be given to non-homogeneous traffic involving trucks and passengers vehicles.

Problem Statement

During incidents and bottlenecks the upstream traffic flow is not aware of the upcoming reduction in capacity and therefore continues at the same speed till the shock wave brings the flow at standstill leading to stop and go traffic that goes beyond the time the incident or bottleneck is removed. In cases of a lane closure vehicles in the blocked lane are forced to stop and then push themselves into the open lanes cutting down the speed of flow in those lanes leading to a capacity drop at the outlet of the bottleneck. The presence of truck traffic makes these effects more pronounced due to the size and slower dynamics of trucks when compared with passenger vehicles. From the dynamical point of view the system operates as an open loop system and is susceptive to all kind of instabilities which in the case of traffic lead to congestion, capacity drop and inefficiencies that affect mobility, safety and the environment. The design of feedback control strategies which can improve mobility and safety while reducing the impact on the environment by better controlling traffic flow during incidents and bottlenecks is very important and feasible due to developments in connectivity and ITS technologies in general.

Variable speed limit (VSL) and ramp metering (RM) control strategies can adjust the mainline flow speed and the ramp flow rate in order to control the vehicle densities in each road section thus improve the traffic condition. However, existing VSL and RM control strategies have shown inconsistent results in microscopic simulations and field tests. In some cases, the travel time is improved and in others deteriorated due to traffic flow control. The major reason of these inconsistencies is the fact that the effect of forced lane changes at bottlenecks is not captured by the macroscopic models that are used to design VSL and RM control, as lane changes are a microscopic phenomenon. In this project we identified this problem and proposed an integrated VSL, RM and Lane Change (LC) control strategy which eliminates or heavily reduces forced lane changes, homogenizes traffic density and speed and leads to steady state traffic that corresponds to the maximum possible flow at the bottleneck. These properties in turn guarantee smaller travel times through the network, less stop and go traffic and lower emissions and fuel consumption especially in the presence of truck traffic.

Research Methodology

The first-order cell transmission model (CTM) of traffic flow along consecutive multiple highway sections is used to model the dynamical characteristics of traffic. The model assumes that vehicle density and flow speed within a single section is homogenous but different in different sections. The flow rate through the bottleneck of a road segment is decided by the vehicle density in the immediate upstream section of the bottleneck and the maximum possible flow rate is achieved at a critical density level. To improve traffic mobility and the environmental impact at bottlenecks and during incidents we like to stabilize the vehicle densities in each section at the equilibrium point where the maximum possible bottleneck flow and the homogeneity of density and flow speed along the entire road segment are achieved. We use the CTM to develop an integrated variable speed limit (VSL), Ram Metering (RM) and Lane Change (LC) control strategy which can maximize the flow at the bottleneck, homogenize density and flow across all sections while reducing travel times and stop and go traffic.

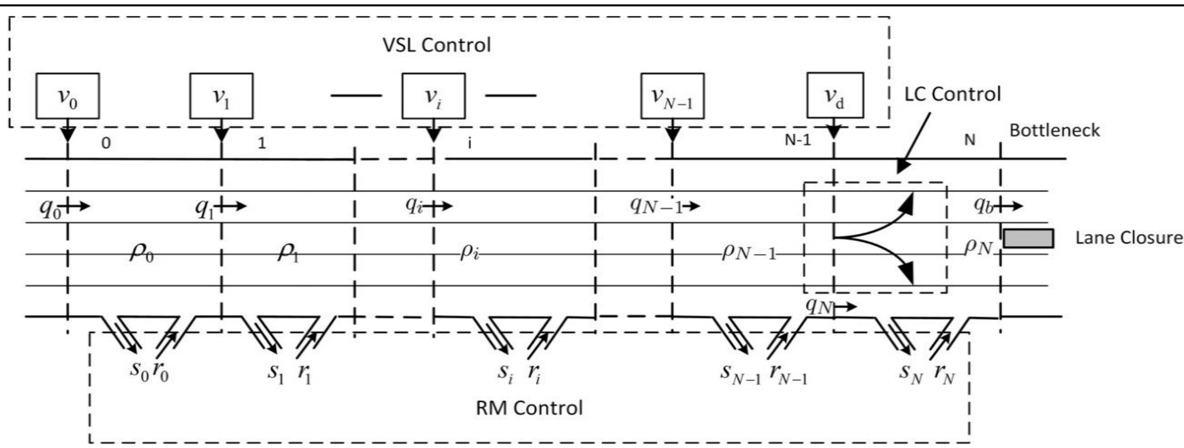

Figure 1 Integrated VSL, RM and LC Control

The configuration of the integrated VSL, RM and LC controller is shown in **Error! Reference source not found.**, where the road segment under control is divided into N+1 sections. VSL controls the speed limit v_i and RM controls the on-ramp flow r_i in section i respectively. LC provides lane change recommendations to the upstream vehicles. Given that the forced lane changes of vehicles in the queue reduce the overall flow speed, we introduce LC controller which provides lane change recommendations to upstream vehicles so that they can change lanes while in motion and therefore minimize the impact on the flow speed of the open lanes. We developed an empirical formula that defines the point along the sections where the lane change recommendations will be given and this point is a function of the demand as well as the number of lanes closed. The relation between the vehicle density in section N and the bottleneck flow is plotted in Figure 2. It is clear that the LC control reduces or even eliminates capacity drop at the bottleneck and allows VSL control to dynamically adjust the incoming traffic to stabilize the densities in

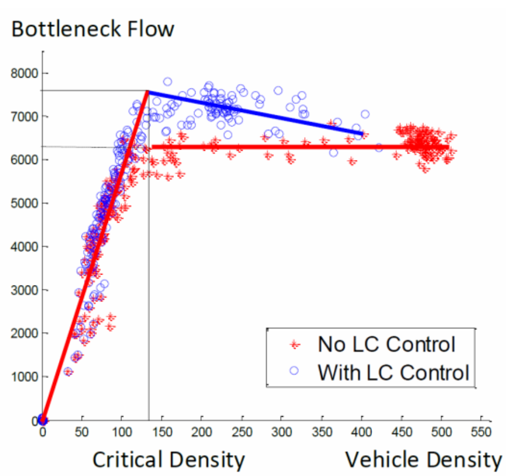

Figure 2 Bottleneck Flow w/ and w/o LC Control

each section at the desired equilibrium value which corresponds to the maximum possible bottleneck flow. The RM controller adjusts the on-ramp flow into the mainline based on both the mainline density and the queue length on the ramp. If the density in the mainline section is high, RM reduces the ramp flow to give priority to the mainline flow. If the queue length on the ramp is large, RM increases the ramp flow to avoid the queue from spilling back to the arterial roads. Meanwhile the VSL controller will decrease the mainline flow to give priority to the ramp flow. The VSL control design is based on a nonlinear control technique known as feedback linearization which allowed us to analytically prove the stability properties of VSL control.

Numerical results

We implemented the integrated VSL, RM and LC controller and evaluate its performance using the microscopic traffic simulator VISSIM for the traffic on a segment of the I-710 freeway in California (between I-105 and the Long Beach Port) with an overall demand of 6000 vehicles per hour which contains 15% trucks. Figure 3 shows the bottleneck flow with and without the integrated traffic flow controller. Compared to the no control case, the integrated controller can keep a higher flow rate after the incident happens at 5 minutes. Although the flow rate without control increases faster after the incident is removed at 35 minutes, the simulation results in

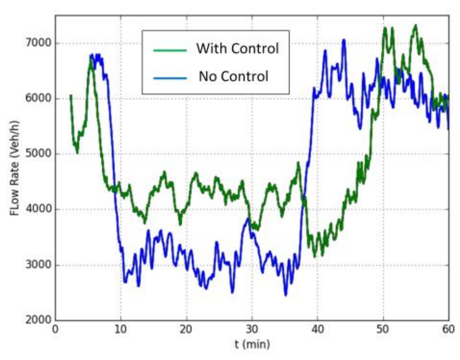

Figure 3 Bottleneck Flow

Table *1* show that the integrated controller decreases the average travel time of each vehicle by 27% thus improves the traffic mobility and reduces the number of lane changes and stops which have positive implications on traffic safety. Furthermore, the fuel consumption rate and the CO2 emission rate is consistently reduced in Monto Carlo simulations.

Table 1 Evaluation Results

Control Type	No Control	RM	VSL + LC	RM + VSL + LC	Improvement
Average Travel Time(min)	15.7	14.8	12.0	11.4	27%
Average Number of Stops	23.3	23.9	4.2	4.2	82%
Average number of Lane Changes	5.1	5.0	4.8	4.6	10%
CO2 (g/veh/mi)	585	580	548	538	8%
Fuel (g/veh/mi)	187	184	175	172	8%