Providing More Sustainable Semi Actuated Intersections through the Development of an Eco-driving application for Connected and Autonomous Vehicles

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Background

The USA has the largest share of global fuel consumption with a share exceeding 20%. Since the 1980's, the electric power consumed by residential and industrial sectors within the USA has maintained almost the same level of consumed petroleum, unlike the transportation sector where the consumption values have been increasing. Moreover, the transportation sector is becoming the major consumer of the USA national petroleum with a share of about 75% and total consumption of finished motor gasoline of about 143.37 billion gallons in 2016. These statistics motivated researchers to develop numerous applications for making the transportation sector more sustainable in terms of fuel consumption and greenhouse emissions. Among these applications, eco-driving has proved to be an effective tool for reducing fuel consumption rates by achieving smooth speed profiles and reducing unnecessary accelerations, decelerations, and idling situations.

The rapid development in Connected/Automated vehicles (CAV) and communication technologies provides opportunities for vehicle-to vehicle (V2V) and vehicle-and-infrastructure (V2I/I2V) communications. With such communications, traffic signals can broadcast Signal Phasing and Timing (SPaT) information to drivers, and drivers can broadcast their speed, acceleration, and coordinates, which helps develop more effective eco-driving applications. The review of the literature reveals a great deal of eco-driving applications for fixed-time signals. However, developing eco-driving applications for semi-actuated signals is more challenging due to variations in cycle length in response to fluctuations in traffic demand from the intersection approaches. Semi-actuated signals are widely used in the USA at intersections that are part of a coordinated corridor in urban intersections. The literature review indicates that developing accurate eco-driving applications for semi-actuated signals is lacking.

Objective

This study utilizes the available communications in the CAV environment in order to develop an eco-driving application (Eco-Semi-Q) for semi-actuated intersections. This application is capable of providing more sustainable intersections by reducing fuel consumption and greenhouse emissions.

Methodology

Since actuation of semi-actuated signals occurs only on minor road approaches, the Eco-Semi-Q model reduces the fuel consumption levels for vehicles traveling through the major approach by optimizing their trajectories. The algorithm assumes a CAV environment and makes use of the V2I/I2V and V2V communication to obtain the required data. The Eco-Semi-Q requires the installation of an additional detector at the intersection minor approach(s). The additional detector is installed 300 m upstream of the stop line for each approach and sends the time, speed, and headway of arriving vehicles to the associated controller cabinet (or Road Side Unit) on a real-time basis. The Eco-Semi-Q comprises the following modules:

Signal Timing Prediction Module:
Once a vehicle is detected by the additional detector on the minor approach, the time at which this vehicle is expected to reach the common actuation detector is estimated. Consequently, a more accurate prediction for the signal timing on major approach(s) can be achieved.

Queue Estimation Module:
This module accounts for the queue length due to traditional and CAV while calculating the optimal trajectory.

Trajectory Optimization Module:
This module utilizes results from the previous modules and applies a brute-force algorithm to optimize the vehicle trajectory and minimize the fuel consumption of individual vehicles. An experience-dictionary is integrated within the optimization model to achieve, after several simulations, adequate performance on a real-time basis.

Results

The simulation was executed in PTV-VISSIM where actions were passed from the model to the simulation platform using VISSIM -Com interface. The results confirmed the effectiveness of the developed model in providing more sustainable semi-actuated intersections with less vehicle fuel consumption and emission. In particular, the saving in fuel consumption associated with controlled vehicles was about 29.2% compared to the case without control. Moreover, a sensitivity analysis was conducted to evaluate the impact of market penetration (MP), and the results indicated that saving in fuel consumption increases proportionally with the increase in market penetration level, with an overall saving of 20% over the entire network at 100% market penetration. Furthermore, when the MP is greater than 50%, the model provides some savings in travel time. Finally, the results from the developed model were utilized to estimate the acceleration noise for guided vehicles and were found to be 21.9% less than that for the case with no guidance. This reduction in fuel consumption and acceleration noise is a promising indicator for reducing vehicle emissions.