Integrated Traffic Signal and Vehicle Trajectory Control in a Mixed Traffic Condition

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Introduction

➢ Traffic signal control plays an important role in intersection management to regulate traffic flows and ensure safety.
➢ With the connected and automated vehicle (CAV) technology, the speed of the CAVs can be planned in a fuel-efficient way with the information from the infrastructure.
➢ This study proposes an integrated control scheme to optimize the traffic signals and control the CAVs in a mixed traffic condition with regular vehicles (RVs), and connected vehicles (CVs).
➢ A state transition diagram is designed for different modes of operations of CAVs, a mixed-integer linear programming (MILP) problem is formulated to optimize the traffic signal parameters and the arrival time of CAVs.

Simulation Framework

➢ The overall simulation framework consists of four modules: VISSIM microscopic traffic simulator, Infrastructure Algorithms module, CAV Algorithms module, and Post Analysis module.

CAV module

➢ A CAV transition diagram is proposed which includes five different states and control models for a CAV: free flow, intelligent follow, optimized control, stop and launch.
➢ In the free flow and coordinated launch state, CAVs are controlled by the Intelligent Driving Model (IDM).
➢ In the intelligent follow state, CAVs formulate platoons and the acceleration is determined by a Cooperative Adaptive Cruise Control (CACC) model.
➢ In the optimized control state, a trigonometric speed profile format is applied to plan eco trajectories with four scenarios:

Post Analysis Module

➢ Fuel/energy consumption and emissions are calculated by the MOVES model.
➢ Customized emission rate tables are retrieved from the Michigan region.
➢ This module is implemented in VISSIM’s Emission.dll API.

Infrastructure Module

Traffic State Estimation

➢ The queuing profile, including the vehicle queuing dynamics for CAVs, are predicted by shockwave theory and/or input-output model.
➢ A green window, in which CAV platoons can pass the intersection is predicted based on the queuing profile and SPA T data.

Integrated Optimization

minimize \( \sum_{k} \sum_{j} \sum_{q} D_{kj}^{q} \)

s.t. \( D_{kj}^{q} = k_{j} \frac{v_{arr}}{v_{max}} - d_{kj}^{stop} + (q-1)h_{CACC}v_{kj} \)

Signal constraints

General time of arrival constraints

CACC specific time of arrival constraints

➢ The objective is to minimize total delay and improve the efficiency of the intersection.
➢ Decision variables include signal parameters and the arrival time of the CAVs at the intersection.
➢ Signal constraints mainly represent the standard NEMA dual-ring barrier structure.
➢ Time of arrival constraints for all vehicles are used to determine whether a vehicle can pass the intersection in the current green or the next green phase.
➢ CACC specific time of arrival constraints determine split of CAV platoons.

Simulation Results

➢ The intersection of Plymouth Rd. and Murfin Ave. (Ann Arbor, MI) is built in VISSIM and calibrated with real-world traffic volume data.
➢ Actuated Signal control is used as baseline.

Scenario 1: CAV + CV

Scenario 2: CAV + RV

➢ The integrated control scheme reduces delay and fuel consumption, and it achieves more benefits with a higher penetration rate of CAVs.
➢ The delay reduction can be as high as 18.7% under high penetration rate of CAVs.