DRISI
Caltrans Division of Research, Innovation and System Information

Research Notes

Advanced Research

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Project Title:
Connected and Automated Vehicles Cross Cutting Research

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A Roadmap For Flow Smoothing Via Connected And Automated Vehicles(CAV) In California

Provides a technical framework to demonstrate flow smoothing on vehicles with low levels of automation, to reduce energy impacts of congestion.

WHAT IS THE NEED?

Caltrans is conducting this research to pave the deployment of Connected and Automated Vehicles (CAVs) in California. For the decades to come, traffic flow on California freeways will be composed of mixed-autonomy traffic (i.e. traffic in which some level of automation co-exists with human driven vehicles). In this mixed autonomy traffic, a small proportion of vehicles with some levels of automation will have the ability to smooth traffic, thereby decreasing the negative impacts of congestion (i.e. energy inefficiency, GHG emissions and accidents).

Caltrans has a multi-decade long background in working on automation of traffic (busses, trucks and cars). University of California (UC), Berkeley through the Institute of Transportation Studies has a long history of collaboration with Caltrans on these topics. Caltrans can lead the technology and policy ecosystem for the future of automation, by demonstrating the benefits of actuation of traffic flow by automated vehicles. This will in turn influence policy to push for environmentally friendly automation of traffic, aligned with the environmental goals of California.

This project is part of a broader coalition funded by the US Department of Energy, the National Science Foundation and several actors in the private sector (General Motors and Toyota). The current project will provide a specific California angle to the work, by pushing for deployments in California. It will accelerate the conversations and collaborations between various stakeholders in the State, in particular the private sector, academia, and State agencies.

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WHAT ARE WE DOING?

The research team will first develop a suite of robustness tests (ranging from easy to difficult) in simulation so that they can confidently deploy vehicles in situ on California freeways. The work will involve developing a simulation environment which exhibits traffic waves in a range of settings. They will investigate several possible sites in California (I-210 and I-680 in particular).

The researchers will implement the controllers develop on two Toyota Rav-4's equipped with comma.ai interface packages that UC Berkeley is in the process of purchasing through various other funds. The workflow will include a code translation step (from Python to Simulink) and a verification unit test to confirm the expected actuation outputs from the vehicle. They will perform a series of tests and collect data from the tests.

Furthermore, the research team will perform experiments will help ascertain the deficiencies of the controllers on a specific California freeway, probably I-210 or I-680. They will analyze the collected data and pre-define key performance indicators to determine the efficacy and robustness of the controllers, which may include (but not limited to) change in fuel economy, standard deviations in velocity and acceleration profiles, throughput, network speed, etc.

WHAT IS OUR GOAL?

The goal is a set of successful tests in California on a freeway, demonstrating the ability to smooth traffic flow successfully, based on the use of several vehicles inserted in traffic. The researchers will demonstrate the ability to perform mixed-autonomy control of flows in a way that can improve the negative impacts of congestion.

WHAT IS THE BENEFIT?

Today, a large variety of mainstream vehicles (e.g., Toyota RAV-4) come standard with some degree of automation (e.g., automatic cruise control, lane departure steering assist, etc.), while the technology available in state-of-the-art high-end vehicles (e.g., Tesla) enables the coordination of multiple level-2 enabled vehicles to smooth traffic. The research team is part of a larger consortium aimed at deploying wave-smoothing CAVs into live congested traffic in order to reduce the system-level energy consumption.

In the past, our consortium partners have demonstrated that a rudimentary hand-designed controller (dubbed the FollowerStopper) which was capable of smoothing waves in a controlled ring road experiment and thereby reducing the energy consumption of the system by up to 40%. Meanwhile, the team at UC Berkeley took a different approach; leveraging large scale computational resources and deep reinforcement learning algorithms, which have demonstrated the capability of learning controllers to robustly achieve these goals in simulation. Together, we have developed large scale simulations of freeways and demonstrated even at that scale the ability to smooth traffic waves and improve system-level fuel economy.

As a part of that overall thrust, the goal of this project specifically is to advance our understanding of policy transfer from simulation to reality and to demonstrate it in California. The I-210 testbed could be a specific deployment site. We are also envisioning some Bay Area Centric test sites, such as I-680, I-880 or I-80. In order to bridge the ongoing deep-reinforcement learning research to real-world implementation, the research team seek to perform robustness testing in the form of controlled small-scale tests on California roadways in 2021. These small-scale tests will simultaneously serve as a seed for future CAV deployments and traffic research in the State of California.

WHAT IS THE PROGRESS TO DATE?

The project is in contract execution phase.

The preliminary work of our team has demonstrated that such a reduction is already possible, with a test run in a preliminary form in Arizona, leading to the 40% reduction mentioned above (see Figure below). Our current numerical simulations, leveraging the I-210 Connected Corridors model (see Figure below) already indicate that 10% reduction in energy consumption is possible with a 5% penetration rate of level-2-enabled CAVs on that freeway.

The ambitious goals of the project will be achieved through a combination of computational development, vehicle technology deployment, and highway infrastructure construction. Novel research is being conducted in all of these areas by our interdisciplinary team. Specific major research tasks achieved so far include:

1. Develop high-fidelity simulation tools that exhibit realistic traffic instabilities. These have been developed in Aimsun and SUMO leveraging models already built on behalf of Caltrans District 7.
2. Discover new techniques in multi-agent reinforcement learning. This has been done leveraging the framework FLOW developed at UC Berkeley, and the advances in microsimulation.
3. Develop control algorithms to transfer reinforcement learning policies to connected and autonomous vehicles. This is done using the comma.ai platform, which has enabled us already to demonstrate the approach on Toyota RAV4s already owned by UC Berkeley.
4. Develop, calibrate, and validate energy models for vehicles. This has been achieved through a collaboration with Argonne National Laboratories, with help of their high-fidelity modeling software Autonomie.

IMAGES

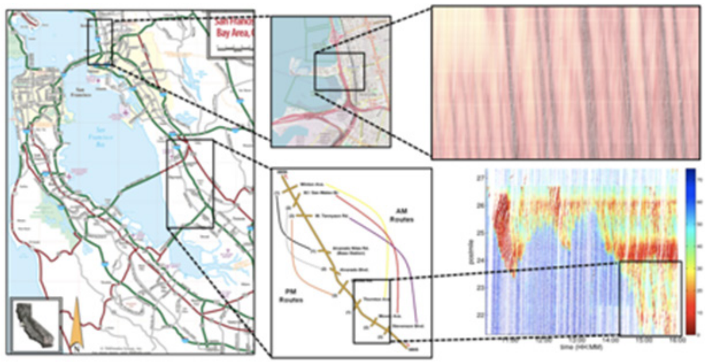

Figure 1. Example of two data sources pioneered by the California Department of Transportation in the past decade. Top: NGSIM data collected in Emeryville, with high resolution static video data for freeways. Bottom: Mobile Century data, the first large scale data collection of GPS data from mobile phones for freeways.

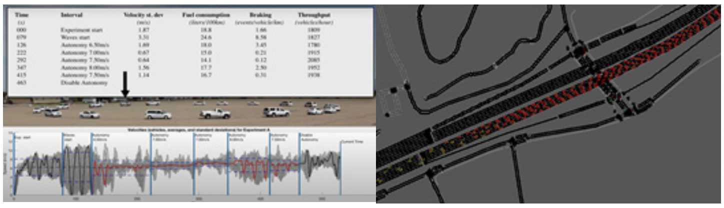

Figure 2. ***Left***: Flow smoothing performed in Arizona, in which a single CAV was able to reduce the energy consumption of a 21 vehicle ring (watch video here);
Right: simulated baseline model of the I-210 Connected Corridors pilot in California, in which extensions of similar algorithms show the prospect of up to 10% reduction in energy by actuation of 5% of CAVs.