Control of Vehicular Traffic Flow via Low Density Autonomous Vehicles

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PROJECT GOAL: DAMPING TRAFFIC WAVES

- Traffic instabilities such as *stop-and-go* waves increase the risk of accidents and adversely affect fuel consumption.
- Such instabilities have been shown to arise even in the absence of geometric bottlenecks on the roadway as shown by Sugiyama, et al. [1].
- Conduct experiment to demonstrate the ability of a single AV to dampen traffic waves locally.

Research question: *How much can a single autonomous vehicle contribute to locally preventing stop-and-go waves?*

From stop-and-go traffic with all human drivers

To smooth flow with human drivers + a single AV

CAT VEHICLE

Autonomous Vehicle

The AV being used in this project as an experimental testbed is the CAT Vehicle from the University of Arizona.

The CAT Vehicle is a 2008 Ford Escape Hybrid which has been instrumented with sensors and actuators to drive autonomously.

The CAT Vehicle with SICK laser scanner mounted on the roof.

Servers in the trunk of the CAT Vehicle that control the vehicle.

Members of the research team at a field test in Tucson, Arizona in December, 2015.

EXPERIMENTAL EFFORTS

Experiments are conducted with up to 22 human drivers and a single AV on a circular track in Tucson, AZ.

In all experiments, all vehicles start under human control. Once waves have developed, the CAT Vehicle is switched to autonomous driving and begins dampening traffic waves [2].

Experiment crew in field experiments at the University of Arizona.

Vehicles on track in Tucson, Arizona in preparation for traffic experiment on a circular ring-road track.

VEHICLE CONTROLLERS

Two different controllers are tested on the CAT Vehicle

PI Controller with Saturation

A PI controller with saturation is implemented. The PI controller commands a velocity:

$$v_{j+1}^{\text{cmd}} = \beta_j(\alpha_j v_j^{\text{target}} + (1-\alpha_j) v_j^{\text{lead}}) + (1-\beta_j) v_j^{\text{cmd}}$$

Where v_j^{target} is determined by the average traffic speed, v^{cmd} is the commanded AV velocity, and α_j and β_j are model parameters with time index j.

FollowerStopper Controller

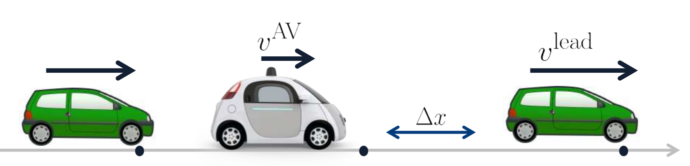
The goal of the FollowerStopper controller is to command the average traffic velocity whenever safe, and command a lower velocity if safety requires:

$$v^{\text{cmd}} = \begin{cases} 0 & \text{if } \Delta x \le \Delta x_1 \\ v\frac{\Delta x - \Delta x_1}{\Delta x_2 - \Delta x_1} & \text{if } \Delta x_1 < \Delta x \le \Delta x_2 \\ v + (U - v)\frac{\Delta x - \Delta x_2}{\Delta x_3 - \Delta x_2} & \text{if } \Delta x_2 < \Delta x \le \Delta x_3 \\ U & \text{if } \Delta x_3 < \Delta x\,. \end{cases}$$

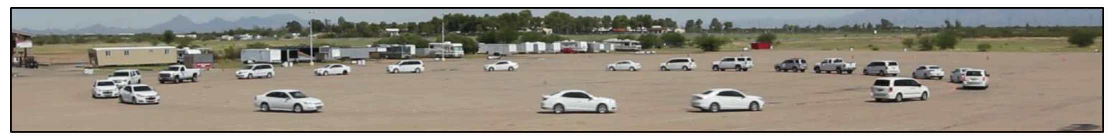
$$v = \min(\max(v^{\text{lead}}, 0), U)$$

$$U = \frac{1}{m}\sum_{j=1}^{m} v_j^{\text{AV}}$$

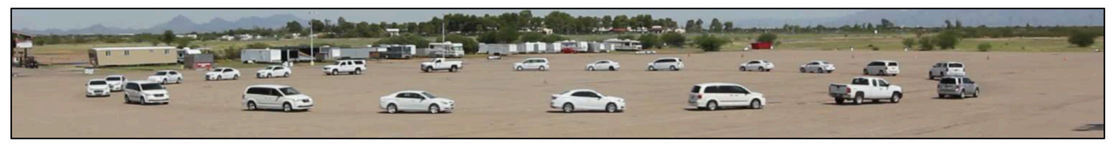
$\Delta x_1, \Delta x_2, \Delta x_3$, are safety distance parameters and m is the time number of measurements.



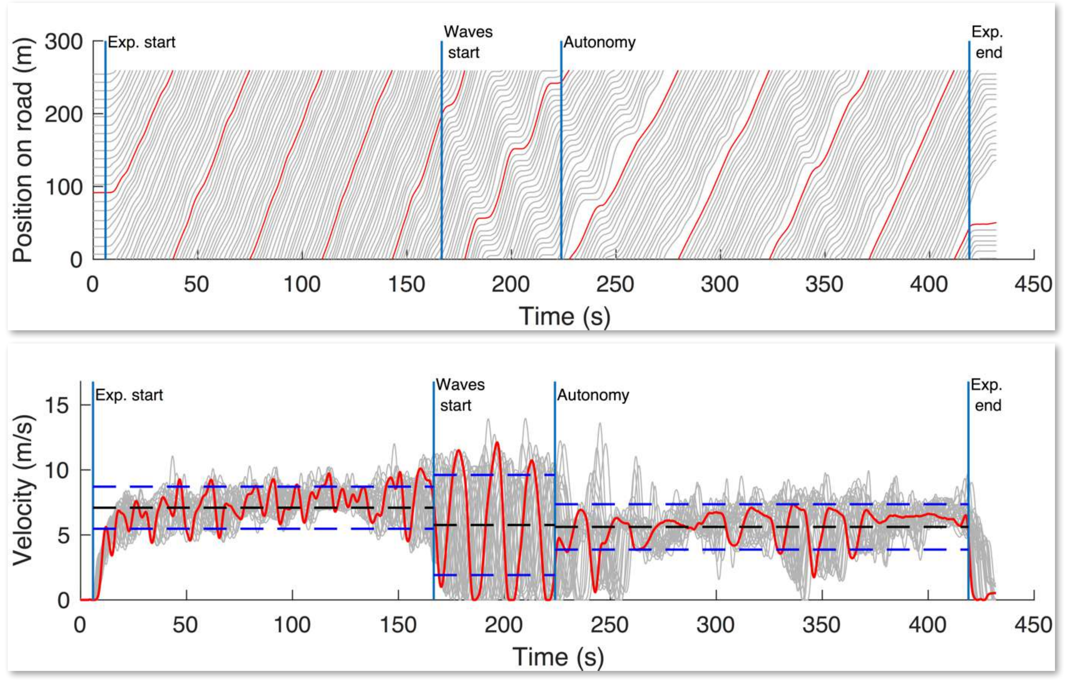
EXPERIMENTAL RESULTS



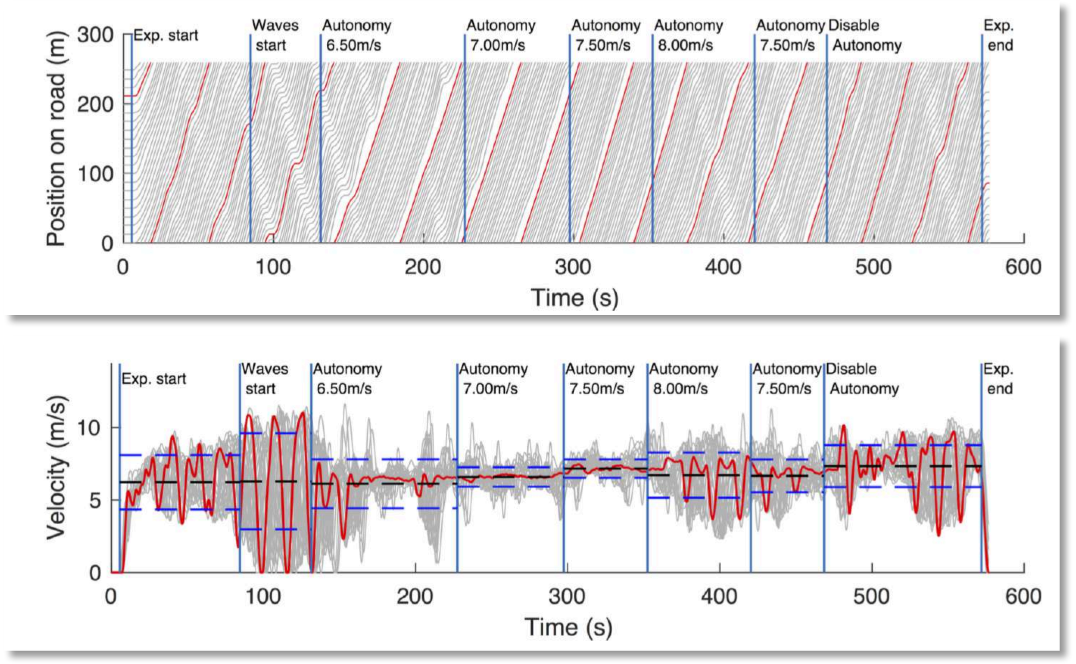
Development of traffic wave with all vehicles under human control.



Smooth traffic resulting from single AV dampening waves.



Vehicle trajectories and velocity profile when using PI controller.



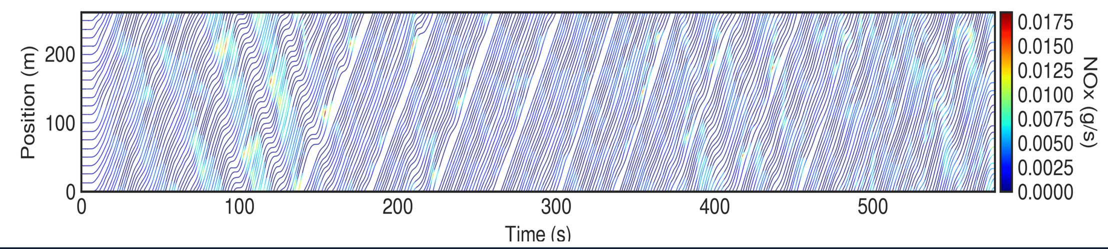
Vehicle trajectories and velocity profile when using FollowerStopper controller.

- Total **velocity standard deviation** reduction: 80.8% ↓
- **Fuel consumption** reduction: 39.8% ↓
- Total **braking** events reduction: 98.6% ↓
- **Throughput** increase: 14.1% ↑

IMPACT OF AV ON EMISSIONS

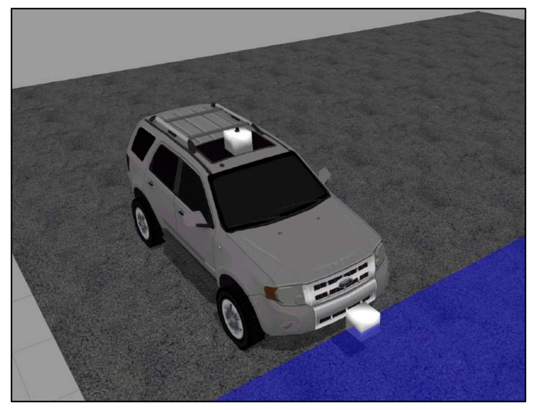
Use emissions model to estimate emissions

By using the VT-Micro microscopic emissions model, we are able to identify up to 45% reduction in traffic emissions.

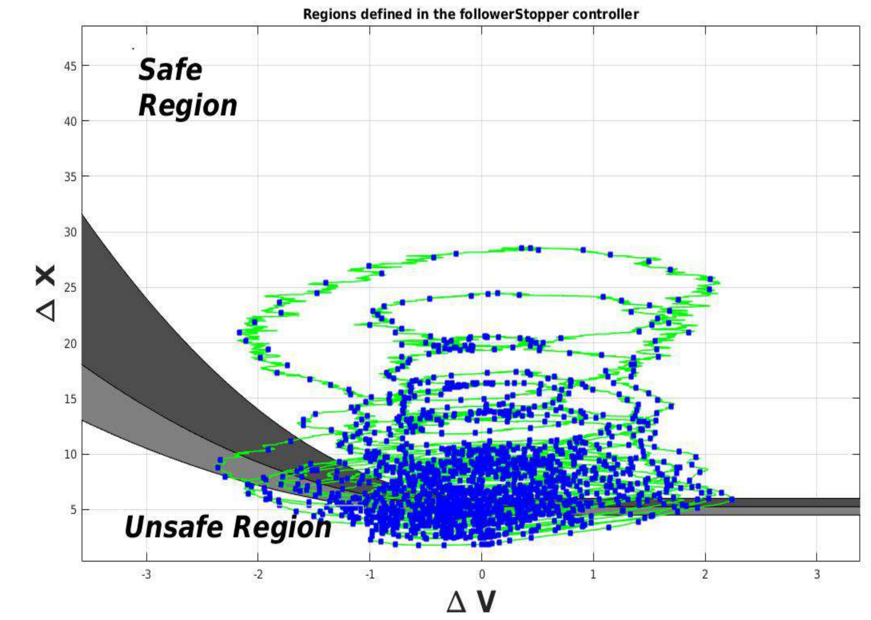


ANALYSIS OF CAT VEHICLE PERFORMANCE

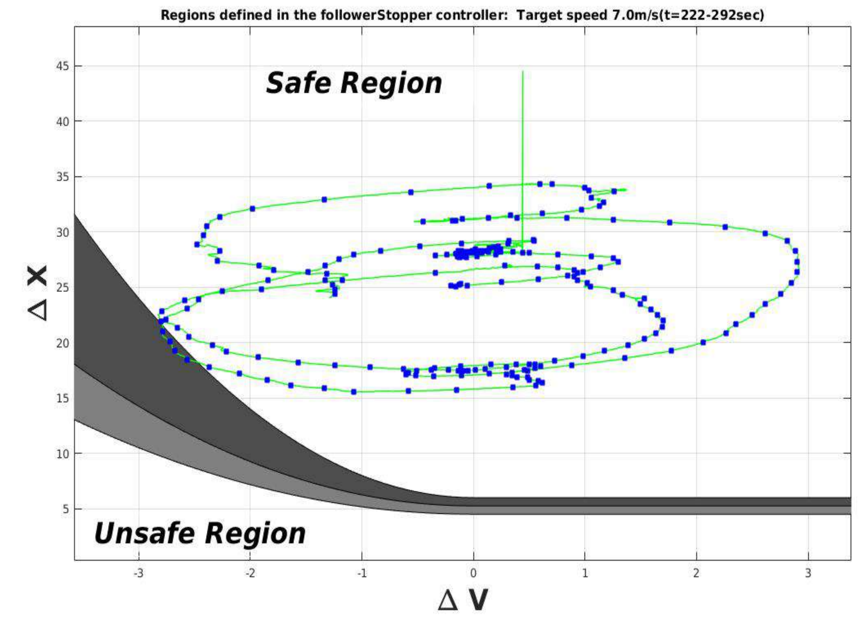
Controllers are simulated in Gazebo simulation to analyze theoretical performance of CAT Vehicle.



Data collected from CAT Vehicle during the experiments is used to analyze how the controller changed the performance of the CAT Vehicle during the experiments.



Δv–Δx phase space analysis without controller on.



Δv–Δx phase space analysis with controller on.

REFERENCES

[1] Y. Sugiyama, et al. Traffic jams without bottlenecks – experimental evidence for the physical mechanism of the formation of a jam. *New Journal of Physics*, 10(3), 2008.

[2] R. Stern, et al. Dissipation of stop-and-go waves via control of autonomous vehicles: Field experiments. *arXiv*, 2017.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant Numbers: CNS-1446702 (Work), CNS-1446690 (Seibold), CNS-1445715 (Piccoli), & CNS-1446435 (Sprinkle).