WiP Abstract: Stabilizing traffic with a single autonomous vehicle

R. Stern* & D. Work
University of Illinois
*Corresponding author
stern5@illinois.edu

S. Cui, H. Pohlmann, & B. Seibold
Temple University

M. L. Delle Monache & B. Piccoli
Rutgers University

J. Sprinkle
University of Arizona

ABSTRACT

This work focuses on technologies for *cyber-physical systems* (CPS) to mitigate traffic instabilities that adversely affect fuel consumption (e.g., stop-and-go waves) via precise velocity control of a small number of *autonomous vehicles* (AVs) on the highway. The main finding is that even a single autonomous vehicle may substantially reduce undesirable traffic waves in its vicinity when properly controlled. The general approach is to use AVs and their sensors to detect congestion events, and then close the loop by carefully following prescribed velocity controllers that are demonstrated to reduce the fuel consumption of the overall traffic flow.

Related work. Stabilizing traffic flow via technology has been an important research theme over the past fifty years [1]. Our work fundamentally differs from past stability analyses in that: (a) large deviations from equilibrium (i.e., established nonlinear traffic waves) are considered; and (b) only a single AV may be available to drive the system back towards equilibrium.

Model of human drivers. Stop-and-go traffic waves are nonlinear phenomena that have been demonstrated to arise even in the absence of bottlenecks [2]. In order to the dampen traffic oscillations via a single AV it is necessary to have a model of human drivers that exhibits these properties. This work considers one such *car-following* model, which is a combined *optimal-velocity-follow-the-leader* (OV-FTL) model:

$$\ddot{x}_j = a \cdot (V(\Delta x_j) - \dot{x}_j) + b \cdot \frac{\dot{x}_{j+1} - \dot{x}_j}{\Delta x_j^2} + \varepsilon. \qquad (1)$$

In (1), $\ddot{x}_j$ is the acceleration of vehicle j, which is determined by an optimal velocity function V, the headway Δx_j, the velocity $\dot{x}_j$, the velocity of the vehicle ahead $\dot{x}_{j+1}$, and a model noise ε. The parameters a and b, as well as V and ε are calibrated using vehicle trajectories from [2] to reproduce the observed traffic waves.

Stabilizing traffic flow. As a first step, a stabilizing linear feedback control law is derived, but then applied to the system even when far from equilibrium:

$$\ddot{x}_j = a \cdot (V(\Delta x_j) - \dot{x}_j) + b \cdot \frac{\dot{x}_{j+1} - \dot{x}_j}{\Delta x_j^2} + c \cdot (u_{eq} - \dot{x}_j)\,, \qquad (2)$$

where c is the control gain and u_{eq} is an estimate of the equilibrium velocity.

Simulations show that a single AV can dampen all traffic waves on a one-lane ring road with 21 human-controlled vehicles. Hence, AV penetration rates as low as 5% may be sufficient to eliminate traffic oscillations. Further studies show that lower AV penetration rates can substantially reduce the magnitude of traffic waves, even if they are not fully eliminated.

Future work. Next steps are focused on experimental validation of the model and controller using high resolution data collection and actuation enabled by the *Cognitive and Autonomous Test* (CAT) vehicle at the University of Arizona. Fully nonlinear controllers are also being developed for (1).

Acknowledgments. This work supported by NSF CNS awards 1446715, 1446435, 1446690, and 1446702.

1. REFERENCES

[1] R. Wilson and J. Ward. Car-following models: fifty years of linear stability analysis – a mathematical perspective. *Transportation Planning and Technology*, 34(1):3–18, 2011.

[2] 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):033001, 2008.