Effects of limited acceleration capabilities on connected automated vehicles

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Abstract: *Heterogeneous connected vehicle systems, which include connected human-driven vehicles as well as connected automated vehicles, are investigated at linear and nonlinear level. Delays due to human driver reaction, vehicle-to-vehicle (V2V) communication, and throttle/brake actuation are incorporated into the car-following model. Saturations due to limits of acceleration and breaking of the vehicles are also taken into account. This leads to new dynamic behavior, where bistability between uniform flow and traffic waves appears. The skeleton of the traffic dynamics is drawn as a three-dimensional wire frame. It is demonstrated that utilizing long-range wireless vehicle-to-vehicle (V2V) communication the connected automated vehicle is able to eliminate the oscillations and make the uniform flow globally stable.*

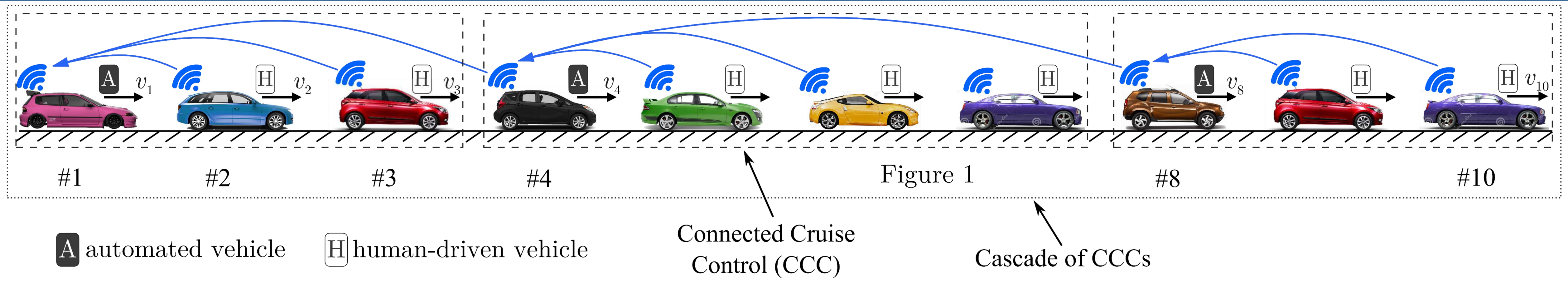


Figure 1

Introduction

- Many prior research assumes 100% penetration rate of automation and connectivity in road transportation.
- Connectivity is expected to spread rapidly in the next few years, automation will likely follow in a slower pace.
- There is a need to understand the dynamics of **mixed scenarios** where automated vehicles are mixed into the flow of human-driven traffic (Fig. 1).
- Experimental results show that **nonlinearities may play an important role.**
- Sources of the nonlinearities (see Fig. 2): **limited acceleration capabilities, speed limits.**

Car-following model

- Propose a connected cruise control (CCC) algorithm to regulate the **longitudinal dynamics.**
- Utilize motion information from multiple vehicles ahead (within and **beyond the line of sight**).
- Saturations due to speed limit and **limited acceleration capabilities are taken into account.**
- The vehicles placed on a circular road.
- **Reaction and actuation delays** of human-driven and automated vehicles are incorporated.
- The governing equations:

automated vehicle:
$$\dot v_i = f\Big(\alpha\big(V(h_i^\sigma) - v_i^\sigma\big) + \sum_{j=1}^{k_i} \beta_j (v_{i+j}^\sigma - v_i^\sigma)\Big)$$

human drivers:
$$\dot v_i = f\Big(\alpha_h\big(V(h_i^\tau) - v_i^\tau\big) + \beta_h (v_{i+1}^\tau - v_i^\tau)\Big)$$

$$\dot h_i = v_{i+1} - v_i,$$

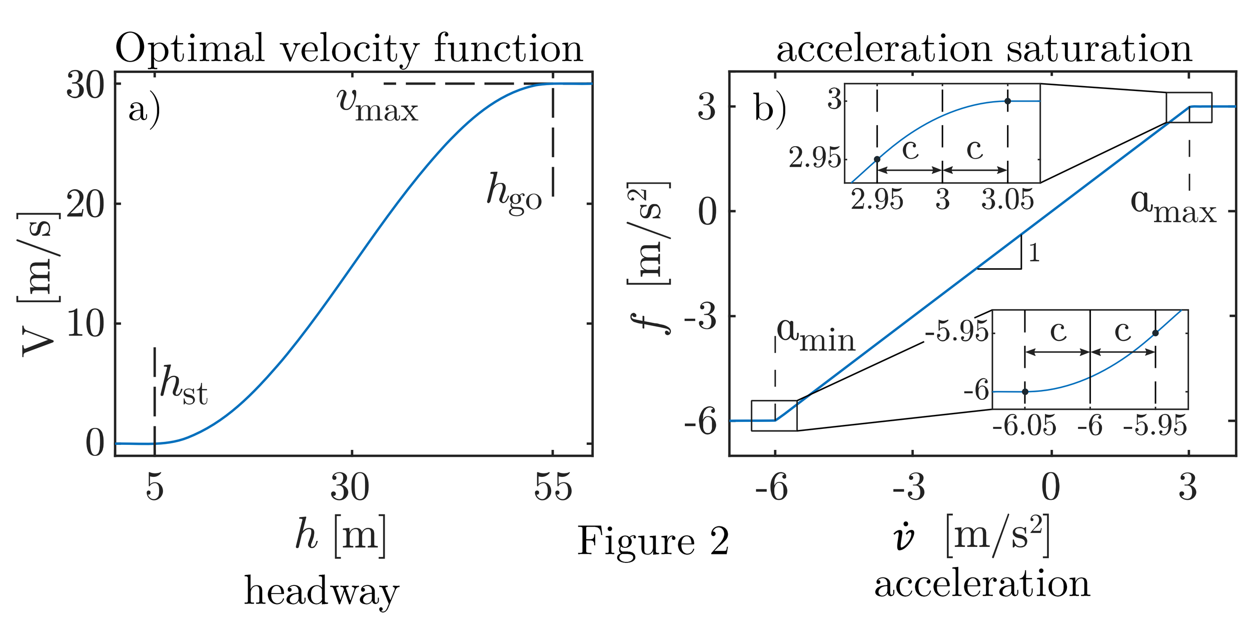


Figure 2

Linear analysis

- Understand the effects of the connected automated vehicles the stability of the uniform flow equilibrium.
- **V2V communication** (using beyond-line-of-sight information) **can improve linear stability** (see light gray areas in Fig. 6).

Nonlinear analysis

For the first time, we demonstrate that **acceleration saturation leads to new dynamic behavior**:

- **bistable regions** appear through the presence of **isola** (see Fig. 3-5).
- Skeleton of the traffic dynamics is represented as a three-dimensional wire frame (see Fig. 4-5).
- **No linear stability loss** occurs, but **larger perturbations may still trigger traffic waves.**
- Including additional information from beyond-line-of-sight (β_2>0), a **connected automated vehicle can make** the uniform flow **globally stable** (see dark gray areas in Fig. 6).

Figure 3

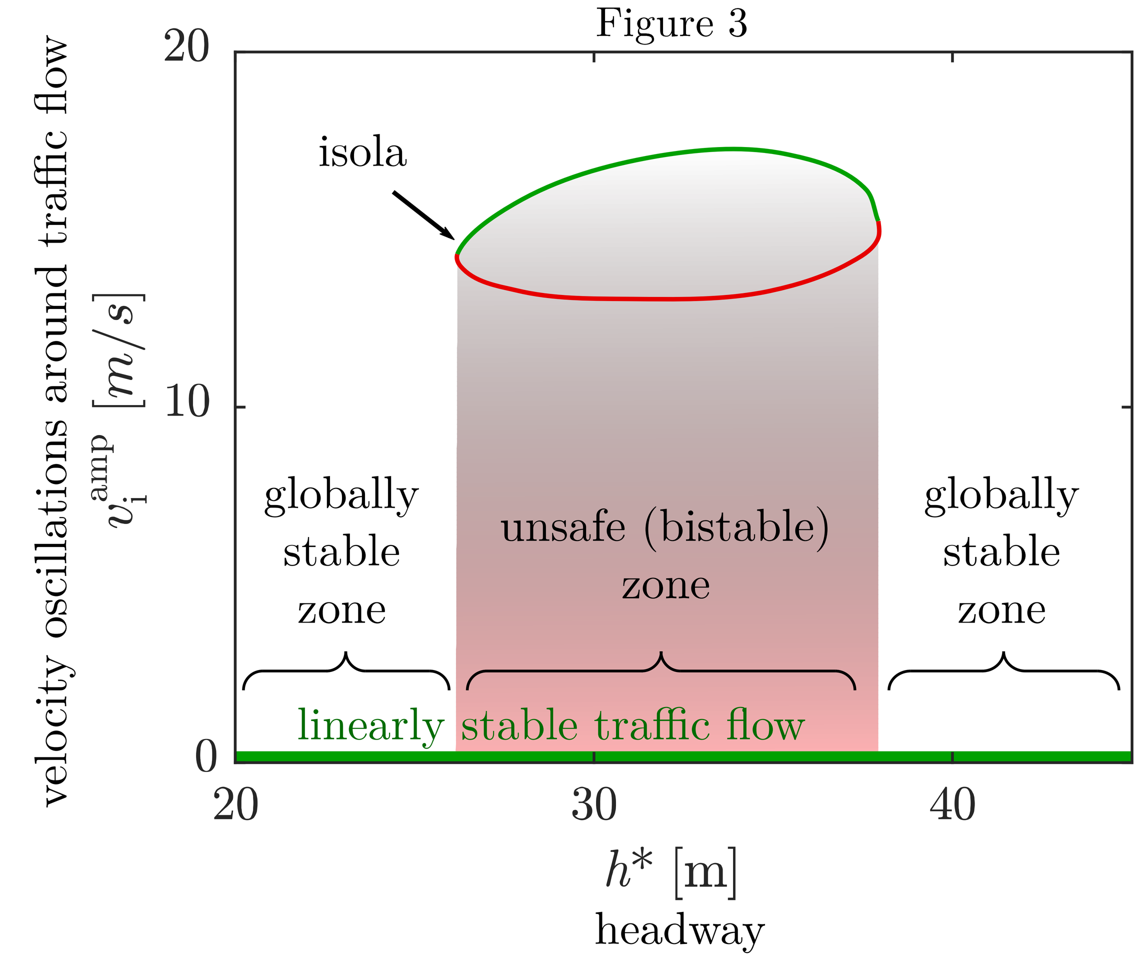


Figure 4

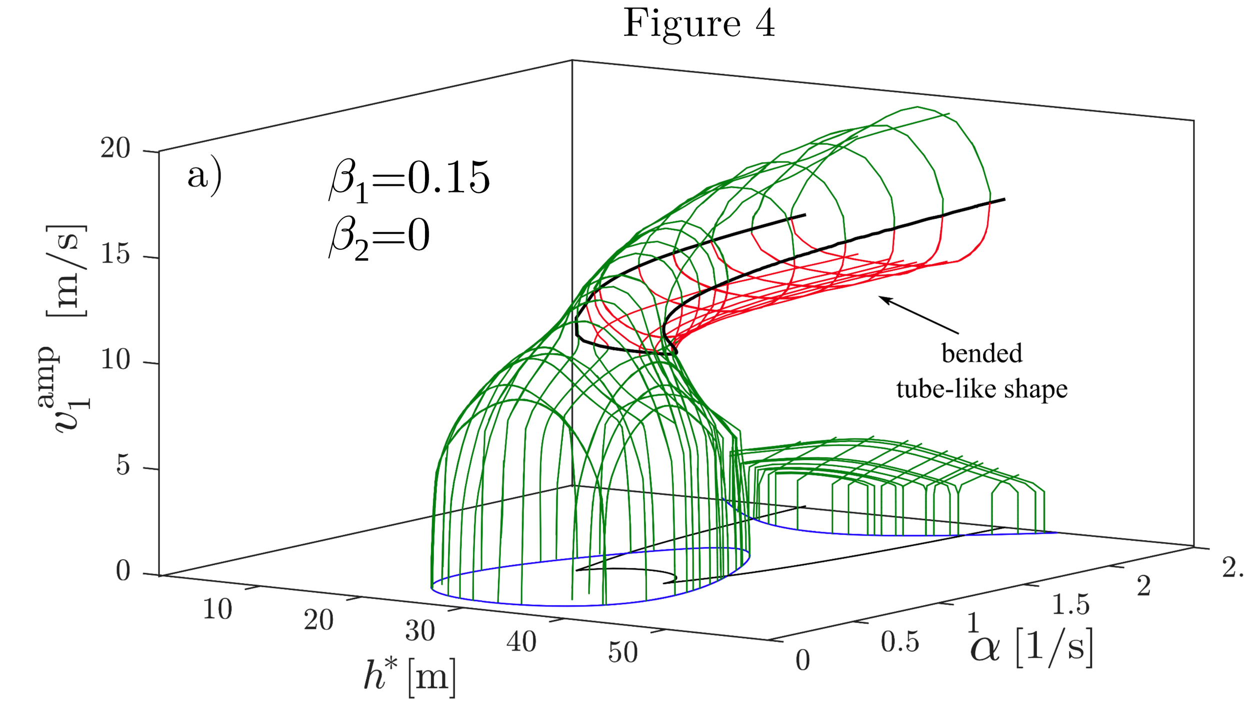


Figure 5

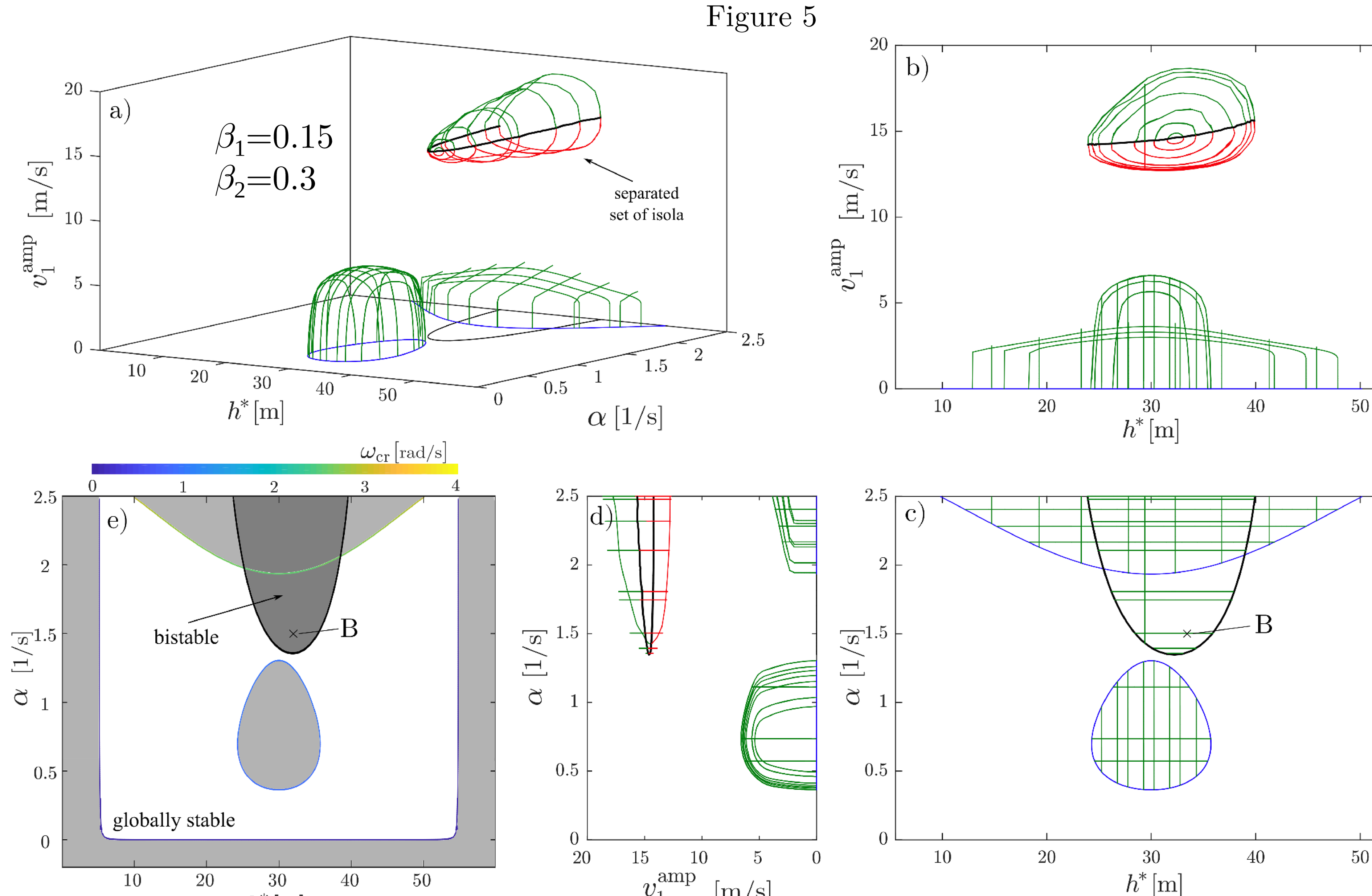
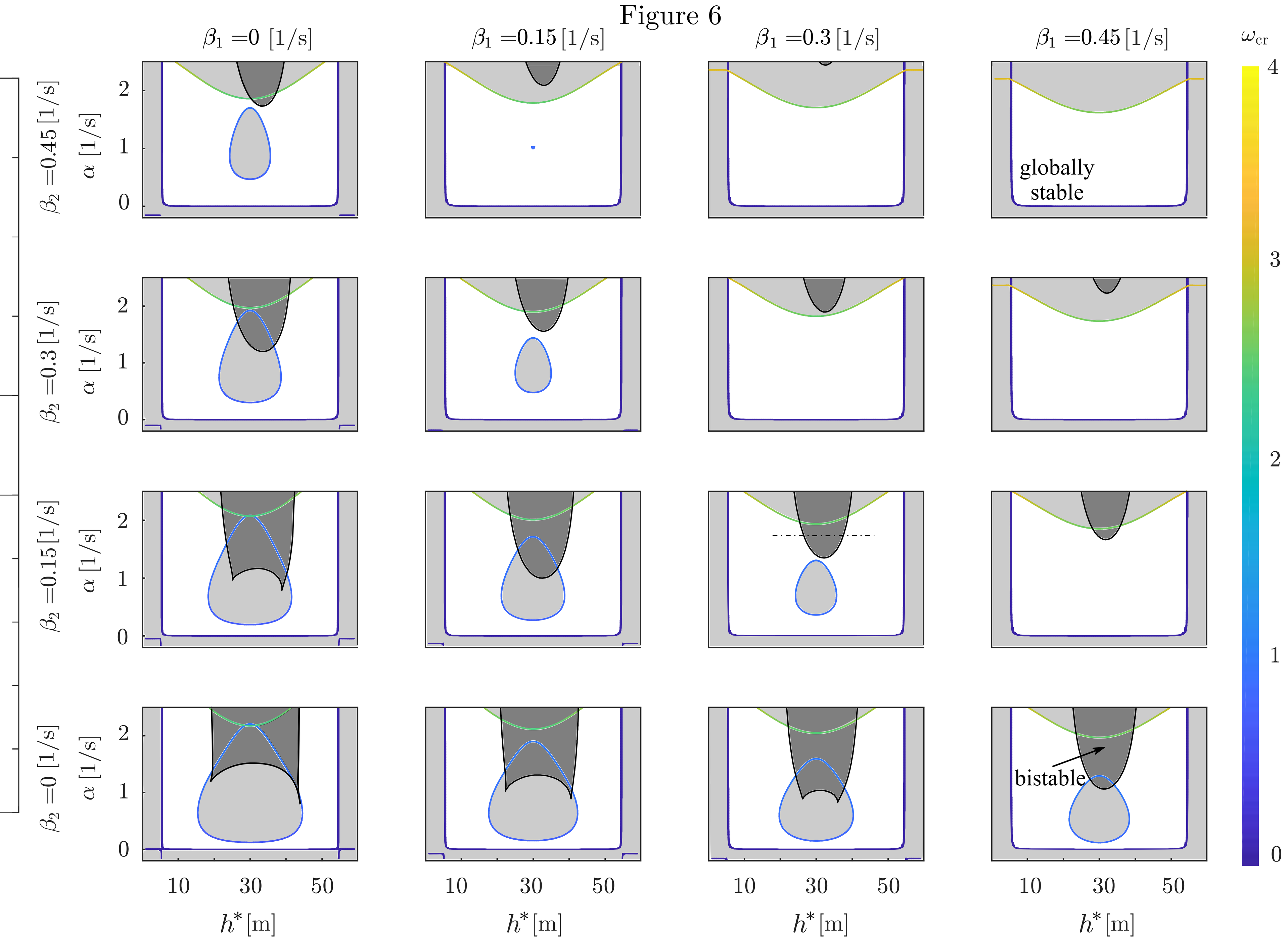


Figure 6



Conclusion

- **Saturations** due to the speed limit and limited acceleration capabilities of the vehicles **result in bistable zone** in the plane of control parameters.
- Linear stability analysis was used to identify regions, where oscillations arise due to loss of stability of the uniform flow equilibrium.
- Bistable regions were determined, where **smooth traffic flow coexists with congested states** (sufficiently large perturbations may trigger traffic waves).
- **Utilizing beyond-line-of-sight information** (via V2V communication), a connected automated vehicle is able to completely **eliminate traffic waves** both at the **linear and nonlinear levels**.

Reference

[1] Kiss, A.K., Avedisov, S.S., Bachrathy, D., Orosz, G.: On the global dynamics of connected vehicle systems, Nonlinear Dynamics (2019), 96(3):1865-1877.

Acknowledgments

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