Network performance of autonomous cars at low market shares

Andrea Vanesa Papu Carrone and Jeppe Rich

Department of Transport, Technical University of Denmark

Bygningstorvet 116B, 2800 Kgl. Lyngby, Denmark,

rich@dtu.dk

Abstract

In this paper we consider how network performance is affected by a mixture of two heterogeneous car classes, a class which is designed to mimic the behaviour of autonomous vehicles (AVs) and a class which is designed to mimic normal driver behaviour. This makes it possible to investigate network effects as a function of the market shares of AVs. It is relevant from a policy and planning perspective as it will support decision making in the long-sighted phasing-in period of AVs.

In the paper, we base the AV class on a non-stochastic formulation of the intelligent driver model (IDM) due to Treiber et al. (2000). This model represents an advanced adaptive cruise control (ADAS) system which is "collision-free" and likely to find its way into autonomous cars. The segment representing normal driving behaviour is based on a modified and stochastic representation of the IDM model. Hence, in the latter model we allow for heterogeneity among drivers and introduce changes to the parametrisation to better reflect normal driver behaviour. We base the parametrisation of the randomness on experimental measurements from the literature.

The hypothesis put forward in the paper is that even moderate to low market shares of AVs could have significant impact on the network performance. Hence, it is possible that AVs can act as "facilitators of smoothness" in the transport system. In congested networks where the car density is high the properties of the AVs will translate to other cars simply as a result of natural v2v dynamics. In a way these cars act in a similar way as optimal speed-postings implemented on many motorways around the world and with a proven record for improving the network throughput. In Copenhagen it was implemented for the M3 motorway and in a before and after study it was evidenced that speed-postings reduced the travel time in the magnitude of 10%.

Keywords: *Autonomous vehicles; transport demand; network effect; heterogeneous car types.*

Methodology

One of the most advanced models for representing vehicle-to-vehicle dynamics is the Intelligent Driver Model (IDM) as proposed by Treiber et al. (2000). The model is essentially developed with the assumption of perfect information with respect to distance to the car in front, its velocity and the velocity difference (its acceleration).

More specifically, the acceleration of the IDM vehicle i at time t is given by $\dot{v}_i(t)$ where

$$\dot{v}_i(t) = a\left(1 - \left(\frac{v_i(t-1)}{v_{i0}}\right)^{\delta} + \left(\frac{s^*(v_i(t), \Delta v_i(t))}{s_i(t-1)}\right)^2\right)$$

The first term compares the current velocity v_i to the desired velocity v_{i0} for vehicle i. In the second term, s^* and s represent the desired gap and actual gap to the car in front and the acceleration is a function of the ratio between these two. The desired gap s^* is given by

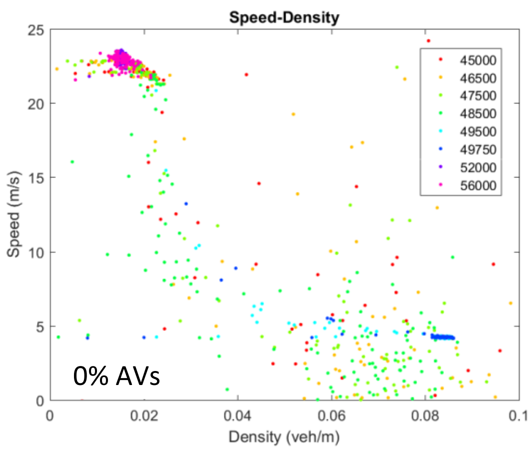
$$s^*(v_i(t), \Delta v_i(t)) = s_0 + Tv_i(t-1) + \frac{v_i(t-1)[v_i(t-1) - v_{i-1}(t-1)]}{2\sqrt{ab}}$$

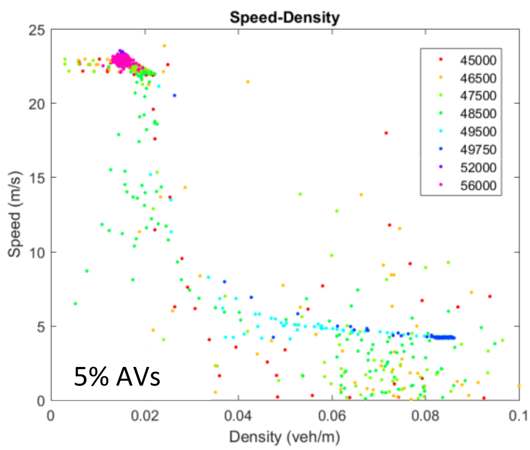
Where s_0 is the minimum physical gap (in meters) and $Tv_i(t-1)$ the safety headway T multiplied by velocity. The final term measures the effect of the velocity difference between the current car and the preceding car whereas a represent the maximum acceleration (m/s) and b a comfortable breaking deacceleration.

Results

The analysis is carried out in a micro simulation model applied to a bottleneck system. The system evaluated in a brute-force Monte-Carlo iterative scheme and fundamental diagrams and performance measures are evaluated for artificial loop detectors.

As seen from the diagrams below, the performance of the system depends on the penetration degree of AVs. For a system without AVs we experience stop-and-go traffic due to the heterogeneity of the different drivers. The fundamental diagram is compared with similar observed fundamental diagrams for Copenhagen and there is shown to be a good correspondence. As we increase the percentage of AVs the performance is significantly improved and for market shares of 50% there is literally no stop-and-go traffic in the system.





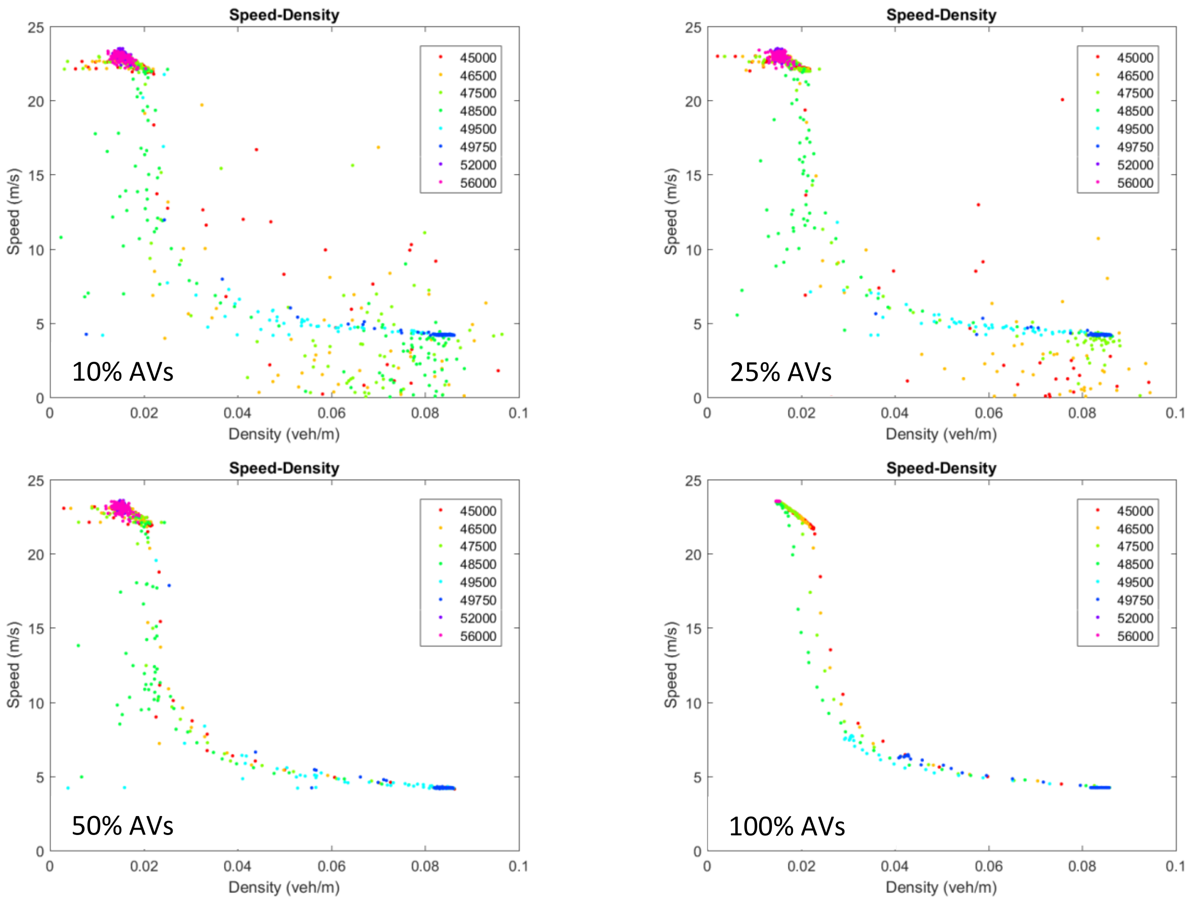


Figure 1: Speed density curves at different market shares of IDMs vehicles.

In the paper we will consider further improvements of the IDM model and investigate in more details the performance gains that may be expected as a function of different AVs market penetration scenarios.