A Queueing Model and Analysis for Autonomous Vehicles on Highways

Abstract

We investigate the effects of autonomous vehicles (AVs) on highway congestion. AVs have the potential to significantly reduce highway congestion, since they can maintain smaller inter-vehicle gaps and travel together in larger platoons than human-driven vehicles (HVs). Various policies have been proposed to regulate AVs, yet no in-depth comparison of these policies exists. To address this shortcoming, we develop a queueing model for a multi-lane highway, and analyze two policies: the designated-lane policy (“D policy”) under which one lane is designated to AVs, and the integrated policy (“I policy”) under which AVs travel together with HVs in all lanes. We use a Markovian arrival process to connect the service rate to inter-vehicle gaps and congestion, and measure the performance using mean travel time and throughput. Our analysis shows that although the I policy performs at least as well as a benchmark case with no AVs, the D policy outperforms the benchmark only when the highway is heavily congested and AVs constitute the majority of vehicles; in such a case this policy may outperform the I policy only in terms of throughput. These findings caution against recent industry and government proposals that the D policy should be employed at the beginning of the mass appearance of AVs. Finally, we calibrate our model to data, and show that for highly congested highways, a moderate number of AVs can make substantial improvement (e.g., 22% AVs can improve throughput by 30%), and when all vehicles are AVs, throughput can be increased over 400%.