Studying the impact of Connectivity and automation in uphill freeway sections

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Introduction

Vehicle automation is progressively introduced in modern traffic networks with technologies that promise to transform the transport sector. New driver assistance technologies are constantly introduced and they will evolve up to a point in which, the complete dynamic driving task can be safely taken over by the vehicle, in every driving situation possible (i.e. the ultimate SAE level 5 full automation). Adaptive Cruise Control (ACC) system is already available in the market and currently, it is considered the closest proxy of full automation regarding the longitudinal movement. In theory, automated functionalities have the advantage to instantly respond whenever needed, minimizing this way the reaction time, which for humans is more than 1 second. However, empirical studies on the estimation of the response time of an Adaptive Cruise Control (ACC) system available in the market proposed by Makridis et al. (Makridis et al., 2018) show that the response time is close to the corresponding human reaction times.

Since information about ACC functionality, parametrization and sensitivity is scarce, most studies assess the impact of such systems through simulation. The accuracy of the model of the dynamic responses of ACC systems is very important in order to output realistic predictions of their effects on highway capacity and traffic flow dynamics (Kesting et al., 2007). Most studies conclude that setting the correct parameters is a difficult task. In parallel, one of the common reasons for capacity bottlenecks in freeway networks are the sections uphill (Ros et al., 2012). Going uphill, drivers reduce speed while they enter the section. When the demand is high they don't compensate for the speed loss and most importantly the perturbation of the platoon leader creates a flow disturbance that it is propagated upstream, leading in cases to a traffic jam.

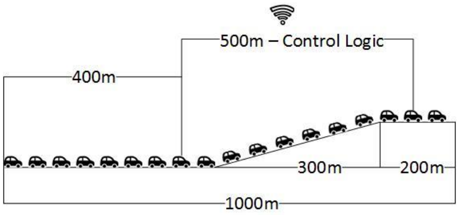

Figure 1. One-lane network, 1km long with an uphill segment of 300 meters. In the figure, it is shown also the area where the control logic is applied.

Simulation and methodology

The main goal of the proposed study is to provide preliminary results regarding the potential impact of automated vehicles in the traffic flow of the future traffic networks and to showcase the impact of vehicle cooperation with the infrastructure. We use a simple one-lane segment and a constant grade uphill in a segment part (see Figure 1). We propose a vehicle dynamics-based car following model based on the Newell's (Newell, 2002) and the MFC free-flow models (Makridis et al., 2019), which is able to reproduce different driver behaviors and can be calibrated for different vehicle characteristics. Afterwards we perform simulations using the Lead Vehicle Problem principle (Daganzo, 2006). The demand of the network consists of different drivers/vehicles from a pool of 125 profiles including both timid and aggressive driving styles (see Figure 2). The simulations are repeated for different random seed in order to validate the results. Since automation in the vehicle is expected to reduce variability in the driver domain, we perform the same simulations using a smaller pool of profiles, considering that each vehicle has its own driving style (see Table I).

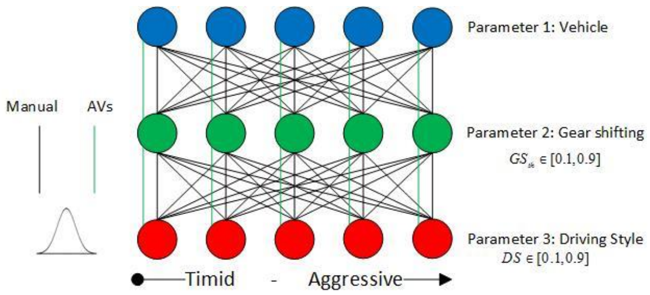

Figure 2. Creation of 125 individual driving profiles $DP_i$by choosing from a pool of 5 different cars, 5 gear shifting strategies and 5 driving styles. AVs are shown with green line and correspond to 5 individual profiles, one per each vehicle. The selection of the profiles during each simulation is performed based on a normal distribution around the average profile, i.e. the second value of each parameter.

This is based on the assumption that its vehicle manufacturer will implement its own ACC logic. Finally, we propose a simple yet efficient control logic to showcase the impact of vehicle cooperation with the infrastructure (V2I). The control logic is based on the results presented by Goñi-Ros (Goñi-Ros et al., 2016), identifying an acceleration maneuver uphill as the best strategy to minimize total delay and facilitate flow. The control strategy is based on the individual capabilities of each vehicle. The control logic is communicated to the vehicle via the infrastructure and instructs the vehicle to acceleration to a percentage of its max potential. In this work we try two collaboration degrees, 60% and 80% of the vehicle acceleration capability. The simulations performed for 2 levels of variability for the ACC drivers and 2 levels of aggressiveness for the control logic. Furthermore, the same simulations are run 2 times for both technologies, one, having response time the same as human drivers and two, reduced by 10% as it is empirically found in our previous work (Makridis et al., 2018).

TABLE I. PARAMETERS PER SCENARIO AND VEHICLE TYPE

	Manual	**AVs**	**Coop-AVs**
Scenario 1	$(DS, GS_{th}) \in [0.1,0.9]$	$(DS, GS_{th}) \in [0.1,0.9]$	$(DS, GS_{th}) \in [0.1,0.9]$ $DS_{coop} = 0.8$
Scenario 2	$(DS, GS_{th}) \in [0.1,0.9]$	$(DS, GS_{th}) \in [0.4,0.6]$	$(DS, GS_{th}) \in [0.4,0.6]$ $DS_{coop} = 0.8$
Scenario 3	$(DS, GS_{th}) \in [0.1,0.9]$	$(DS, GS_{th}) \in [0.4,0.6]$	$(DS, GS_{th}) \in [0.4,0.6]$ $DS_{coop} = 0.6$

Results

Results show that in the highly probable case that different manufacturers will deploy different implementations for their automated systems, the variability introduced by the driver-vehicle duo in future networks will remain in high levels. A reduction in the traffic delays can be expected, especially if the future ACC systems have response times lower than those of humans but the improvement will not be dramatic. On the other hand, cooperation of the vehicles with the infrastructure can play a significant role in future networks. Cooperation even on the basis of timid driving behavior can bring significant improvement in the network increasing the average speed and maximizing the flow. Finally, reduction of the reaction time is simulated by increasing the wave speed and it reveals mixed results. In some cases as expected it improves the throughput but on the other hand, assuming the additional demand the network often approaches saturation leading to capacity drop.

Figure 3 shows the speed over flow results from the Scenario 1. Manually-driven and the automated vehicles have similar performance, while the automated vehicles that cooperate with the infrastructure achieve much higher speeds and throughput leaving the network unsaturated. It is interesting to note that in average numbers the manual vehicles perform better than automated. In the case of reduced response time, the AVs and Coop-AVs often increase the throughput but on the same time the results become less homogenous (greater standard deviation). This practically means that any anticipated benefic depends on the order in which the vehicles enter the network. This observation holds for all the scenarios.

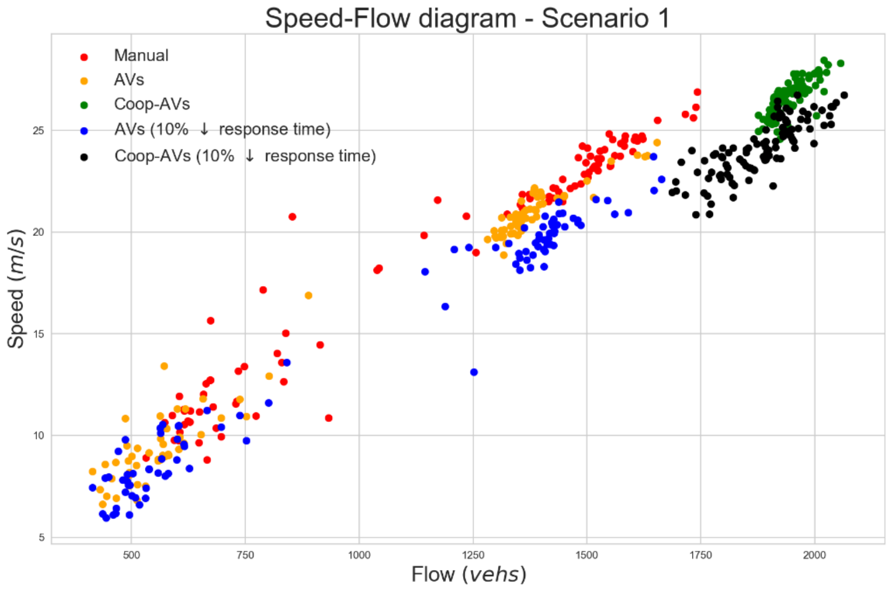

Figure 3. Average speed and throughput per vehicle type and simulation

The evolution of the performance per scenario and vehicle type over the period of 1 hour is illustrated in Figure 4. It is interesting to notice the top figure, in the end of the 1-hour simulation, when the average speed of the Coop-AVs with faster response time is lower than the AVs' speed, although until the 50th minute the situation was the opposite. Furthermore, higher flow are often correlated to lower average speeds. Finally, AVs without homogeneity in their operation underperform over the whole simulation period.

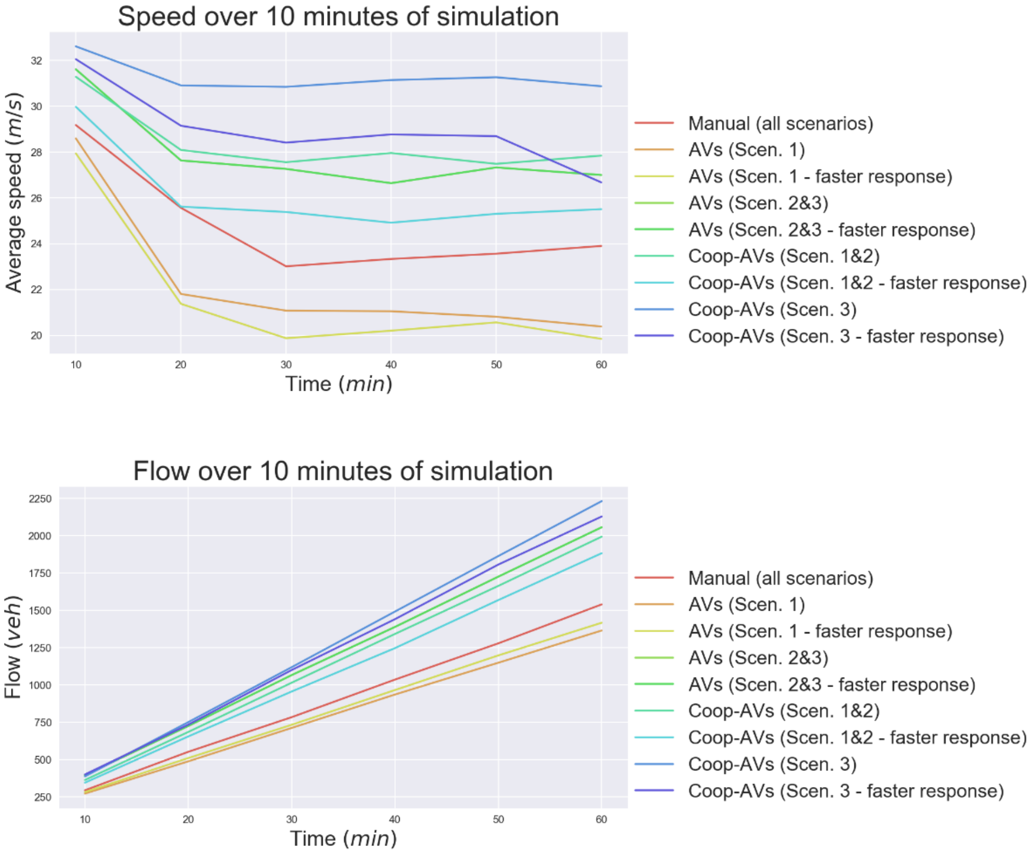

Figure 3. Observations over 10 minutes of simulation showing the evolution of hte average speed (top) and flow (bottom) over the simulation period of 1 hour.

Conclusions

The main conclusions can be summarized as follows:

-The variation in the acceleration of the manual vehicles creates bottleneck in uphill freeway segments.

-AVs are expected to have reduced the variability in the driver’s domain. The more homogenous the AVs are the better they perform.

-Cooperation with the infrastructure can have a very positive impact on the status of the network.

-With reduced response time, the AVs and Coop-AVs often increase the throughput but on the same time the results become less homogenous (greater standard deviation).