Poster: On the Effects of Cooperative Platooning on Traffic Shock Waves

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***Abstract*—Cooperative platooning has been proposed as a promising solution to traffic congestion, safety, and pollution. A platooning application forms road trains of vehicles that autonomously follow a common leader, separated by a small inter-vehicle gap. In terms of traffic efficiency, platooning should improve the vehicular flow and reduce shock waves. The latter are the cause of start-and-stop dynamics which, besides disrupting traffic flow, can lead to accidents. The aim of this poster is to analyze, by means of simulations, the impact of platoons on both the traffic flow and the formation of shock waves.**

I. Introduction and Background

The increase in the number of vehicles in use has led to a huge growth of road traffic, inevitably causing more and more congestion. Traffic congestion increases costs and increases pollution, with consequent health concerns [1]. In addition, a common phenomenon of congested roads is the formation of traffic shock waves, i.e., high-density waves traveling backwards with respect to the cruising direction. They can spontaneously occur even without actual bottlenecks due to small perturbations which are usually absorbed in low traffic densities, but become amplified in high density scenarios [2].

Traffic shock waves clearly represent a threat in terms of safety. They cause sudden emergency braking maneuvers for no apparent reason, and can cause chain collisions when distracted or when not respecting safety distances.

Platooning can be a solution to the problem. With the term platooning we refer to a semi-autonomous driving technology where the vehicles automatically follow a leader, and the members of a platoon travel with a small inter-vehicle gap [3].

One approach to implement platoons is the Adaptive Cruise Control (ACC) [4]. An ACC maintains the cruising speed set by the driver and automatically keeps a safety distance. The ACC does not actually implement platooning, as the time headway[1] that this system maintains is comparable to the one of human drivers (roughly between $1\,\mathrm{s}$ to $2\,\mathrm{s}$).

Smaller inter-vehicle gaps can be realized by means of Vehicle-to-vehicle (V2V) communication. By exchanging data such as current position, speed, and acceleration, the control system can improve its reaction time, so the distance between the vehicles can be reduced without risks for safety. This system is referred to as Cooperative Adaptive Cruise Control (CACC).

The research community proposed different CACC designs. One example is the CACC developed within the California PATH project [4], which exploits wirelessly collected data from the platoon leader and the vehicle in front and maintains a fixed distance between the vehicles. Another approach is the one in [5], where the vehicles only exploit the information sent by the front vehicle. This control system employs a time headway as well, but much smaller (as low as $0.5\,\mathrm{s}$).

These three different control approaches can show the impact of different solutions on the traffic. The ACC maintains a large inter-vehicle gap, but it removes typical human driving imperfections. The CACC proposed in [5], which will be referred to as Ploeg, is similar to an ACC but it drastically reduces the inter-vehicle gap between the vehicles inside a platoon. The CACC in [4], referred to as PATH, drastically improves the road usage by making the inter-vehicle gap speed-independent, transforming a platoon into a single long vehicle.

II. Simulation Setup

We setup our simulations using PLEXE [6], an extension of the Veins vehicular networking framework that enables the realistic simulation of platooning systems. We simulate a $10\,\mathrm{km}$ circular freeway with three lanes where 1080 cars travel with a different target speed, after verifying that the dynamics on a ring are comparable to the ones on a straight road.

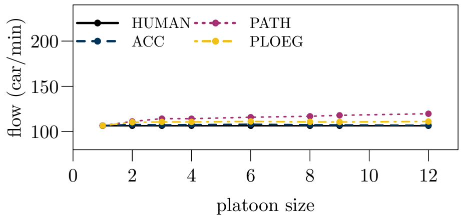
We test the performance of the three described control systems with different penetration rates and with different platoon sizes. Human driven vehicles are controlled by the Intelligent Driver Model (IDM) [7]. We consider market penetration rates of $0\,\%$, $20\,\%$, $40\,\%$, $60\,\%$, and $80\,\%$. For each penetration rate (except $0\,\%$) we inject platoons of different sizes, namely 2, 3, 4, 6, 8, 9, and 12.

Depending on the controller, we have different inter-vehicle distance settings. For human-driven vehicles, we set the time headway of IDM to $1\,\mathrm{s}$, while for the ACC it has been set to $1.4\,\mathrm{s}$. This choice is to highlight that human drivers can keep safety distances lower than the ones of automated systems. For the Ploeg's CACC we set a time headway of $1\,\mathrm{s}$, while for the PATH's CACC we set a fixed distance of $5\,\mathrm{m}$. Each CACC platoon's leader is controlled by an ACC. Finally, we disregard lane changes for platooning vehicles due to the complexity of performing a simultaneous lane change.

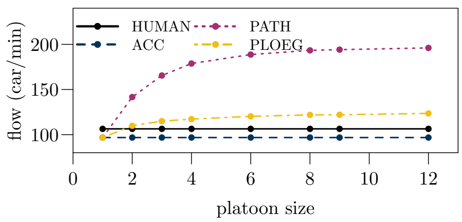
III. Simulation Results

We start our analysis by looking at the impact on traffic flow. Figure 1 shows the flow as function of the platoon size for the different controllers and for two market penetration rates.

[1] A time headway represents a distance in time. The spacing is the time headway times the cruising speed: the higher the speed, the larger the spacing.



(a) 20 % penetration rate



(b) 80 % penetration rate

Figure 1: Traffic flow as function of the platoon size, for different penetration rates.

The first observation is that, for small market penetration rates, the improvement in flow is barely noticeable, while for a large market penetration rate there is a bold increase of the traffic flow. With respect to the ACC, for both market penetration rates, the platoon size shows no impact. This is to be expected because the ACC does not form real platoons and each vehicle is basically a stand-alone entity. Besides a barely noticeable improvement in the traffic flow for a 20 % penetration rate, the ACC actually reduces the flow for a higher penetration rate. This is due to the larger time-headway compared to the one set for IDM. To respect a larger time headway the ACC needs to slow down causing the flow to be lower due to the constant density. However, by looking at Fig. 3, which shows the boxplot of the speeds measured during the simulation, it is clear that shock waves completely disappear, and all cars are smoothly traveling at the same speed.

With respect to the Ploeg's CACC, we can see that the improvement in traffic flow for a high market penetration rate is noticeable for platoons as small as three cars, even if the time headway is the same as for human drivers. For a medium-sized platoon (Fig. 2) this improvement is noticeable even for a 40 % penetration rate. Ploeg's CACC also has a positive impact on shock waves, as witnessed by Fig. 3. Shock waves disappear, but the average speed is higher than with the ACC.

Finally, PATH's CACC has the highest positive impact on the flow, even at small penetration rates. For large market penetration rates the flow is almost doubled, even for medium sized platoons. The huge improvement in traffic flow is due to a much higher average speed of the vehicles (Fig. 3). The small and fixed inter-vehicle gap basically transforms a platoon of vehicles into a single long vehicle. This could be interpreted as a reduction of the vehicle density, although with the same number of vehicles. A side-effect of this is that shock waves are not absorbed, so this system improves the flow but might still cause dangerous situations. This could be a consequence of the lane change model. Given that only human-driven vehicles change lane, with the PATH's CACC they have more room

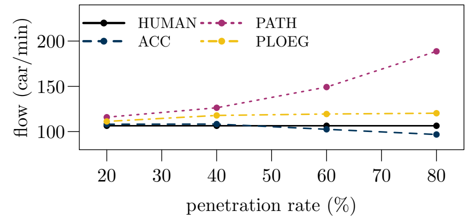


Figure 2: Traffic flow as function of the penetration rate, for a platoon size of 6 cars.

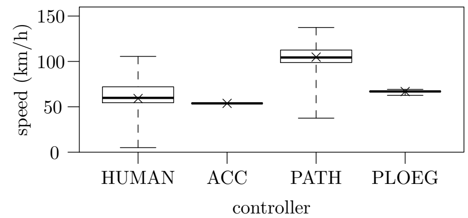


Figure 3: Distribution of vehicle speeds for an 80 % market penetration rate and a platoon size of 6 cars. The box represents the first, second, and third quartiles, the whiskers represent the absolute minimum and maximum, while the cross represents the mean value.

for doing so as platooning vehicles are more packed together. We therefore plan to extend the simulation by enabling lane changes for platooning vehicles as well.

IV. Conclusion

In this paper we studied the impact of different control approaches for platooning on traffic flow and on shock waves. We have shown that systems based on a time headway spacing policy are capable of canceling shock waves in a very effective manner, although with a limited, if not negative, contribution to the flow. A constant spacing policy, instead, greatly improves the flow, although without reducing shock waves too much. Part of our future work will include the introduction of lane changing policies for platoons, as lane changing is one of the known causes of shock waves.

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