2018 IEEE International Conference on Vehicular Electronics and Safety (ICVES)
September 12-14, 2018, Madrid, Spain

On the Impact of Platooning Maneuvers on Traffic

Jesús Mena-Oreja and Javier Gozalvez
Universidad Miguel Hernández de Elche (UMH)
UWICORE laboratory, http://www.uwicore.umh.es
Avda. de la Universidad, s/n, 03202, Elche, Spain
jmena@umh.es, j.gozalvez@umh.es

Abstract— **Previous studies have shown that platooning can improve traffic. In particular, platooning can augment the road capacity, improve the traffic flow, and reduce emissions. However, existing studies do not take into account the impact of platooning maneuvers on traffic. Such impact can be particularly relevant as platooning will be gradually introduced, and automated vehicles will have to coexist with non-automated vehicles. Non-automated vehicles can interfere with the execution of platooning maneuvers, and hence have an impact on the benefits of platooning. In this context, this study analyzes for the first time the impact of platooning maneuvers on traffic (flow and speed) in mixed traffic scenarios where automated and non-automated vehicles coexist. The study demonstrates that the traffic benefits obtained with platooning can be overestimated if platooning maneuvers are not properly modelled and taken into account during the analysis.**

Keywords—Platooning, maneuvers, autonomous driving, automated driving, simulation, SUMO, Plexe, mixed traffic, traffic flow, traffic speed.

I. INTRODUCTION

Automated driving will have a major influence in future transportation systems and mobility services. Automated driving will rely on technologies like Cooperative Adaptive Cruise Control (CACC) and platooning. CACC is an evolution of Adaptive Cruise Control (ACC) that automates the vehicle longitudinal dynamics using radar measurements and information received wirelessly from other vehicles. Platooning is a driving mode where vehicles drive close to each other and form platoons or convoys. The platoons are organized and managed using CACC and cooperative wireless communications. Previous studies have shown that platooning increases the road capacity, and reduces air drag, fuel consumption and emissions [1]. The study reported in [2] also demonstrated that platooning can almost double the road capacity. The study analyzed the impact of platooning on traffic considering different penetration rates of platooning and various platoon lengths; the length is the maximum number of vehicles that can form a platoon.

The studies that have analyzed the impact of platooning on traffic generally simulate traffic scenarios with platoons already formed and that never dissolve. The studies do not consider the impact that the execution of platooning maneuvers might have on traffic. Such impact is partly due to the time needed to execute platooning maneuvers. Vehicles involved in a platooning maneuver might have to accelerate, decelerate or change lanes during the execution of a maneuver that is hence not immediate. For example, [3] estimates that the merge of two platoons can last more than 15s. The leave maneuver for a vehicle in the middle of a platoon can also last more than 7s [3]. The duration and execution of a platooning maneuver can also be influenced by the interaction of the vehicles involved in a maneuver with other surrounding vehicles. Such interaction can be particularly relevant if we take into account that the introduction of automated driving will be gradual, and automated vehicles will need to coexist with automated and non-automated vehicles. Such coexistence and the resulting interactions can result in that non-automated vehicles interfere with platooning maneuvers. For example, the formation of a platoon or the merge of two platoons could be interrupted or delayed if conventional vehicles place themselves between the automated vehicles involved in the maneuver. This effect was highlighted in [4] that showed that the formation of a platoon can be delayed by more than 20% and 50% respectively under medium and heavy traffic conditions. All these results highlight that traffic will have an impact on platooning maneuvers, but these maneuvers will also impact, and even disturb, the driving conditions of conventional or non-automated vehicles. Existing studies have not jointly considered all these effects when quantifying the benefits of platooning. This study advances then the existing state of the art by presenting what is to the authors' knowledge the first study that quantifies the impact of platooning maneuvers on the traffic flow and speed. This impact is quantified by comparing the traffic flow and speed experienced with and without simulating platooning maneuvers. In the first case, automated vehicles execute platooning maneuvers to form, merge and dissolve platoons. In the second case, platoons enter the simulations already formed, and automated vehicles do not execute any platooning maneuvers. The impact of platooning maneuvers is analyzed under mixed traffic scenarios where automated and conventional vehicles coexist. The study considers varying percentages of automated vehicles in the scenario and different traffic densities. The study has been conducted using PERMIT [5], a SUMO-based platooning simulator developed by the authors and that is available in an open-source repository[1].

The rest of this paper is organized as follows. Section II reviews existing studies that analyze the impact of platooning on traffic. Section III presents the PERMIT simulation platform and the implemented platooning maneuvers, and discusses the interference that non-automated vehicles can

---

This work was supported in part by the local government of Valencia (ACIF/2017/160), and the Spanish Dirección General de Tráfico (SPIP2017-02204).

[1] https://github.com/susomena/PERMIT

produce to these maneuvers. Section IV describes the experimental set up and the evaluation conditions under which this study has been conducted. Section V quantifies the impact of platooning maneuvers on the traffic flow and speed, and Section VI summarizes the main contributions of this study.

II. RELATED WORK

Several studies have analyzed the impact of automated driving on the traffic flow. For example, [6] and [7] evaluate the impact of CACC in mixed traffic scenarios where vehicles with CACC coexist with conventional vehicles. The study reported in [6] concludes that CACC can almost double the road capacity when all vehicles are equipped with CACC. The capacity gains that CACC can provide depend on the penetration rate of the technology. CACC can also increase the traffic speed. In fact, [7] demonstrates that CACC can increase the average traffic speed by 10% under high traffic conditions.

Platooning can also have a positive impact on traffic. This is for example highlighted in [8] where the authors study the string stability of platoons and the impact of platooning on the traffic flow. The study demonstrates in a highway scenario that platooning can increase the road capacity by more than 30% when all vehicles are connected and automated. Smaller gains are observed under mixed traffic scenarios where automated vehicles coexist with non-automated vehicles. Similar conclusions were obtained in [9] where the authors evaluate the impact of platooning on the road capacity and the traffic speed. The study models platoons as long vehicles with the length determined by the number of vehicles in the platoon and the gaps between them. The study demonstrates that platooning augments the road capacity. The gains increase with the length of the platoons and the percentage of automated vehicles in the scenario. For example, [9] reports that platooning can augment the road capacity by 8.6% when 10% of the vehicles are in platoons of 6 vehicles. The improvement in road capacity augments to 18.6% when the percentage of vehicles in a platoon is 20%, and to 9.7% when the length of platoons is equal to 9. [9] shows that platooning also improves the traffic speed. The authors estimate that the traffic speed can increase by 25% if 20% of the vehicles are in platoons and the length of the platoons is equal to 9 vehicles. Another interesting study is reported in [2] where the authors analyze the impact of ACC and platooning on the traffic flow and the traffic shock waves. The authors conclude that while ACC can decrease the road capacity because of its high time headways, platooning increases the road capacity even if platoons are short and the percentage of vehicles in platoons is small. The authors show in a ring road scenario with a fixed traffic density of 36veh/km that platooning can almost double the traffic flow if 80% of the vehicles drive in platoons with eight vehicles. The same study also concludes that ACC eliminates traffic shock waves at the expense of slightly decreasing the speed. On the other hand, platooning can increase the traffic speed at the expense of slightly increasing the traffic shock waves. In particular, the study estimates that platooning can increase the average traffic speed by 83% when 80% of vehicles drive in platoons. However, the distribution of speeds is more scattered with platooning than with ACC.

Platooning might initially be introduced on heavy-duty vehicles. The study reported in [4] shows that platoons of heavy-duty vehicles also have a positive impact on the road capacity and the fuel efficiency of light-weight vehicles even if heavy-duty vehicles only represent 10% of the traffic in a highway. Like in previous studies, this analysis was conducted considering that platoons were already formed when entering the simulation scenario. However, [4] also investigated the impact of mixed traffic on the formation of platoons. Conventional vehicles can interfere with the formation of a platoon if they are placed between the automated vehicles that want to form a platoon. [4] quantifies the impact of this interference, and demonstrates that conventional or non-automated vehicles can increase the time needed to form a platoon by more than 20% and 50% under medium and dense traffic conditions respectively. This result clearly demonstrates that traffic interferes with the execution of platooning maneuvers. This can in turn have an impact on the traffic flow and speed improvements brought by platooning. However, this impact has not been studied before since all studies that quantified the traffic flow and speed benefits of platooning have been conducted without simulating platooning maneuvers (i.e. platoons enter the simulation already formed and never dissolve). This approach can overestimate the gains obtained with platooning. In this context, this study advances the current state of the art by presenting what is to the authors' knowledge the first study that quantifies the impact of platooning maneuvers on the traffic flow and speed.

III. PERMIT AND PLATOONING MANEUVERS

This study is performed using PERMIT, an open-source platooning simulator developed by the authors [5]. The simulator uses the open-source microscopic traffic simulator SUMO [10] and its platooning extension Plexe [11]. PERMIT can simulate platooning maneuvers in mixed traffic scenarios. In particular, PERMIT simulates the join, merge, leave and split platooning maneuvers. During the join maneuver, an automated vehicle joins an existing platoon or forms a new platoon together with another automated vehicle. The vehicle joining can be located behind, in parallel, or in front of the platoon. In these cases, the vehicle joins the platoon at the tail, in the middle or at the front of the platoon, respectively. In the latter case, the vehicle joining becomes the new platoon leader. Two platoons can merge and form a larger platoon using the implemented merge maneuver. In the case that both platoons drive in the same lane, the rear platoon catches the front platoon. On the other hand, if both platoons drive in parallel lanes, they merge into a single lane. One or more vehicles can leave an existing platoon using the leave maneuver. A vehicle may want to leave a platoon if its route does not coincide with the route of the platoon leader. The current implementation can execute the maneuver independently of whether it is the leader that leaves the platoon or a follower. The split maneuver is used to break up a platoon and form two or more new platoons. The implementation in PERMIT of all these maneuvers follows the contributions reported in [3] and [12]. The reader is referred to [5] for a more detailed presentation of PERMIT and the implemented maneuvers.

The execution of platooning maneuvers must take into account the traffic context. In fact, a platooning maneuver can require vehicles to accelerate, decelerate or change lanes. These actions can disturb the driving conditions of nearby vehicles. Nearby vehicles can also interfere with a platooning maneuver and delay its execution. To account for all these conditions, the platooning maneuvers implemented in PERMIT are executed if:

- The relative distance between platoons or automated vehicles involved in a maneuver does not exceed a maximum predefined distance.
- The relative speed between platoons or automated vehicles involved in a maneuver does not exceed a maximum predefined value.
- The total number of vehicles in the platoon (or platoon length) at the end of a maneuver does not exceed a maximum predefined value.
- No other vehicle (conventional or automated) or platoon obstructs a maneuver and represents a risk for its safe execution. A vehicle represents an obstacle for a platooning maneuver if it is in the trajectory of any of the vehicles participating in the maneuver.

A platooning maneuver is aborted if any of these conditions is not guaranteed. Of particular interest to this study is the last condition that refers to scenarios in which vehicles interfere with the execution of a platooning maneuver. Such interference can delay the successful execution of the maneuver or limit the length of platoons, and both effects will impact the traffic flow and speed. A join or merge maneuver between two automated vehicles or platoons driving on the same lane can be interfered if there is a vehicle in between the automated vehicles or platoons involved in the maneuver. When the automated vehicles or platoons involved in the join or merge maneuver drive in different lanes, the rear vehicles or platoons change lanes when they catch the front vehicles or platoons. This maneuver can be interfered if there is a conventional vehicle behind the front automated vehicle or platoon, and the gap between this vehicle and the front automated vehicle or platoon is not sufficient for the rear automated vehicles and platoons to change the lane. This risk of interference increases with the length of the rear platoon. A leave or split maneuver can also require vehicles to change lanes in order to leave a platoon. In this case, a vehicle can interfere with this maneuver if it is located in parallel to the vehicle that wants to leave the platoon.

IV. EXPERIMENTAL SETUP

This study considers a ring road scenario (like in [2]) with a length of 10km and two lanes. The study has been conducted for two traffic densities (36veh/km and 60veh/km) and various percentages of automated vehicles in the scenario (from 0% to 100%). The selection of which vehicles are automated is randomized. The road has ten edges that can represent the origin or destination of the simulated vehicles, and all vehicles have random routes. This modelling approach ensures that automated vehicles will perform different platooning maneuvers during the simulations, and that they will encounter a varying number of vehicles during the execution of the maneuvers.

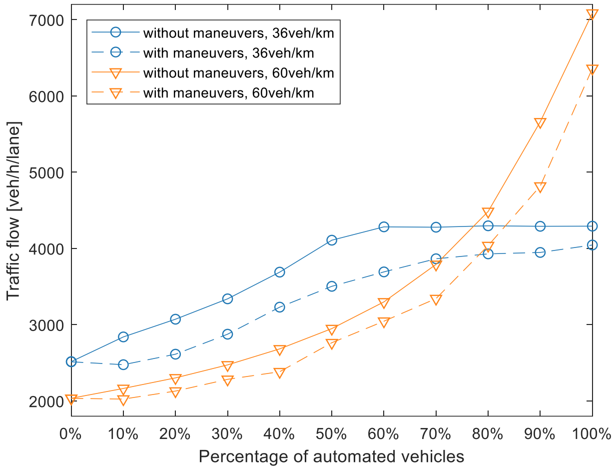
The mobility of conventional vehicles is modeled using the default configuration in SUMO: the longitudinal and lateral dynamics of vehicles are modelled with the Krauss car-following [13] and LC2013 lane-changing [14] models respectively. In this study, the Krauss car-following model has been set up with a time headway of 1s. The lateral dynamics of automated vehicles is also modeled using the LC2013 lane-changing model. Several models are used to implement the longitudinal dynamics of automated vehicles. Platoon leaders and automated vehicles driving outside a platoon use the ACC model implemented in Plexe and defined in [15]. The ACC model is configured with a time headway of 1.4s following [2]. Automated vehicles driving inside a platoon follow the leader, and use the California PATH CACC model implemented in Plexe and defined in [15]. This CACC model is configured to maintain a gap of 5m with the front vehicle as in [2]. The maximum number of vehicles in a platoon (or platoon length) has been set up equal to 8 vehicles following the conclusions presented in [2]. This study showed that larger platoons do not significantly increase the road capacity.

The objective of this study is to analyze the impact of platooning maneuvers on the traffic flow and speed. As a result, the following benchmark simulations have been executed: 1) simulations with 0% of automated vehicles in the scenario (i.e. simulations without platoons), and 2) simulations with platoons of maximum length that enter the simulation already formed and never execute a maneuver during the entire simulations (i.e. simulations without platooning maneuvers).

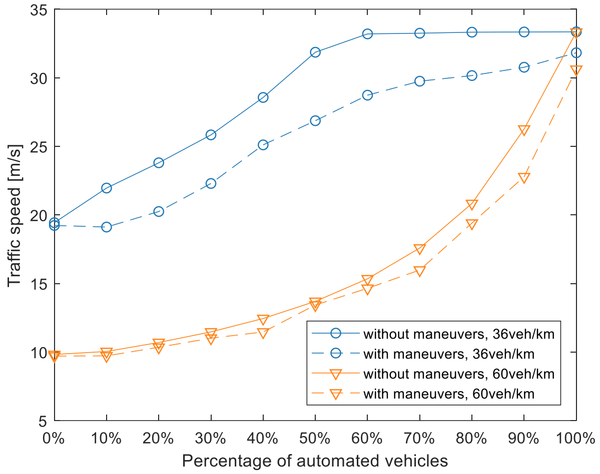
V. RESULTS

Fig. 1 analyzes the impact of platooning maneuvers on the traffic flow and speed. The analysis has been conducted for two traffic densities and different percentages of automated vehicles in the scenario. Fig. 1 represents the traffic flow and speed measured with and without simulating platooning maneuvers. In the first case, automated vehicles execute platooning maneuvers to form, merge and dissolve platoons. In the second case, automated vehicles do not execute platooning maneuvers, and the platoons enter the simulation already formed. Fig. 1 clearly shows that platooning maneuvers have an impact on the traffic, and that it is necessary to take maneuvers into account when analyzing the future impact of automated driving on traffic. In fact, Fig. 1 shows that the benefits of platooning are overestimated if they are quantified without considering the impact of platooning maneuvers. To the authors' knowledge, this is the first study that quantifies such benefits taking into account the effect of platooning maneuvers on traffic.

Section III discussed platooning maneuvers and the conditions that must be met for the maneuvers to be executed successfully. If the maneuvers are executed under the presence of other vehicles (automated or not), the vehicles involved in a platooning maneuver will have to interact with these vehicles. It is possible that such interactions result in a failed platooning maneuver if for example the safety gaps between vehicles are not respected. This interaction and possible interferences

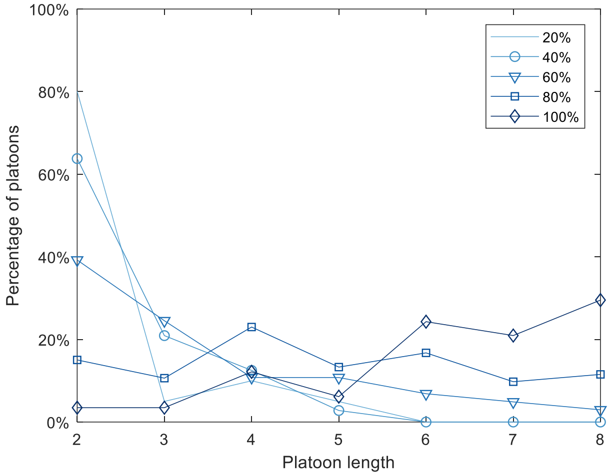


(a) Traffic Flow

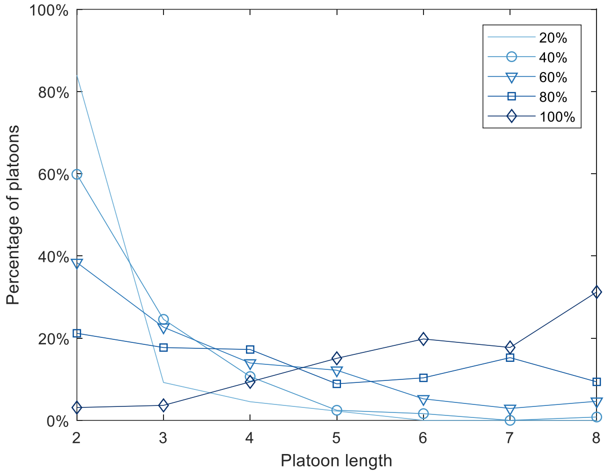


(b) Traffic Speed

Fig. 1. Impact of platooning maneuvers on traffic as a function of the percentage of automated vehicles in the scenario. Results are shown for traffic densities of 36veh/km and 60 veh/km.



(a) Traffic density of 36veh/km



(b) Traffic density of 60veh/km

Fig. 2. Distribution of platoon lengths for different percentage of automated vehicles in the scenario.

explain the differences observed in Fig. 1 between the scenarios in which platooning maneuvers are simulated and those in which they are not. The interferences generated by neighboring vehicles resulted in that many platooning maneuvers could not be executed, and the platoons generally failed to reach their maximum length (especially for low percentages of automated vehicles in the scenario). This is actually observed in Fig. 2 that depicts the distribution of platoon lengths for different rates of automated vehicles in the scenario[2]. Fig. 2 shows that the interaction between vehicles involved in platooning maneuvers and other vehicles result in that platoons cannot achieve their maximum length (eight). Fig. 2 also shows that when the percentage of automated vehicles in the scenario is small, most of the platoons have only two vehicles. When this percentage increases, the number of vehicles per platoon increases, and larger platoons become more frequent than smaller ones. However, even if all vehicles in the scenario are automated, most of the platoons will still have less than eight vehicles under the simulated scenario[3]. The interference generated by neighboring vehicles also causes that some automated vehicles are never able to join or form platoons during the simulations. This is illustrated in Fig. 3 that represents the percentage of automated vehicles that never joined a platoon. This percentage is high when the rate of automated vehicles in the scenario is small since the probability of finding more than one automated vehicle at the same location or area is small. This probability significantly increases with the percentage of automated vehicles in the scenario. However, Fig. 3 shows that there are still many automated vehicles unable to join platoons when the percentage of automated vehicles in the scenario is large. The

---

[2] Fig. 2 corresponds to the scenario implementing platooning maneuvers and that is marked as 'with maneuvers' in Fig. 1. The results marked 'without maneuvers' in Fig. 1 correspond to the scenario where platoons enter the simulation already formed, and automated vehicles do not execute any platooning maneuvers during the simulation. In this case, the length of the platoons is always equal to 8.

[3] The conducted simulations randomize the origin and destination of platoons. As a result, vehicles join and leave platoons during the simulations. These maneuvers and the interaction with neighbor vehicles explain why it is difficult to achieve the maximum platoon length.

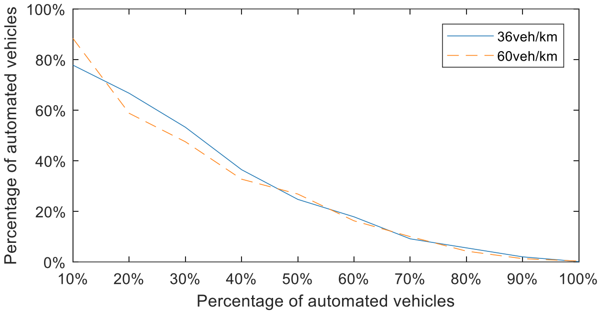


Fig. 3. Percentage of automated vehicles that never joined a platoon.

trends reported in Fig. 2 and Fig. 3 explain the differences observed in Fig. 1, and why studies can overestimate the positive impact of platooning on traffic if they do not take into account platooning maneuvers.

Fig. 1 shows that platooning generally improves the traffic flow and speed. For example, Fig. 1 shows that the traffic flow and speed increase by 22% and 71.5% when there are 20% and 80% respectively of automated vehicles in the scenario (and platooning maneuvers are not simulated) compared to the scenario without automated vehicles. These results are in line with those reported in [2] where the authors estimate that platooning can increase the traffic flow and speed by 20% and 75% when the penetration rate of automated vehicles is 20% and 80% respectively. However, these results are optimistic since they do not consider the impact of platooning maneuvers in traffic. In fact, Fig. 1 shows that when such impact is considered (results labelled 'with maneuvers' in Fig. 1), platooning will not improve the traffic until 20% of vehicles are automated. With only 10% of automated vehicles in the scenario, Fig. 1 shows that platooning slightly degrades the traffic flow and speed ('with maneuvers' in Fig. 1) compared to the case in which there are no automated vehicles. This is the case because the likelihood of creating platoons is low when the percentage of automated vehicles is small. In this scenario, the size of the platoons is also small, which reduces the benefits of platooning. Platooning maneuvers further compromise these benefits since there is a high probability that a platooning maneuver will be negatively affected by surrounding vehicles if most of these vehicles are not automated. In addition, the maneuvers have also an impact on the traffic experienced by a large number of vehicles if these vehicles are not automated and hence their driving cannot be coordinated with the execution of a platooning maneuver.

Fig. 1 also shows that platooning maneuvers have a similar effect on the traffic flow and speed for various traffic densities. However, the differences observed when taking into account or not the platooning maneuvers decrease with the traffic density. For example, considering platooning maneuvers reduces the average[4] traffic flow and speed by 11.5% when the traffic density is equal to 36veh/km. The reduction[4] is equal to 9.4% and 6.2% respectively when the traffic density is equal to 60veh/km. Higher traffic densities reduce the possibility to execute maneuvers for any type of vehicle (whether automated or not). This explains why the impact of implementing platooning maneuvers reduces with the traffic density.

The results depicted in Fig. 1 show that platooning maneuvers always reduce the traffic flow and speed independently of the percentage of automated vehicles in the scenario. The differences observed in Fig. 1 between the simulations implementing or not platooning maneuvers vary between 5% and 15%. In particular, the difference observed for the traffic flow decreases from 15% with a low percentage of automated vehicles to 5% when the percentage increases. This trend is actually due to the impact of the percentage of automated vehicles in the scenario on the length of platoons (Fig. 2). Fig. 2 shows that the length of platoons augments with the percentage of automated vehicles in the scenario. Larger platoons improve the traffic flow which explains why the traffic flow differences observed in Fig. 1 decrease with the percentage of automated vehicles in the scenario. The maximum platoon length has been set up in this study following [2]. This study showed that augmenting the number of vehicles in a platoon increases the traffic flow until a maximum size of eight vehicles per platoon[5]. The conclusions in [2] were obtained without considering the impact of platooning maneuvers on traffic. Fig. 2 shows that when such maneuvers are simulated, the size of the platoons varies with the rate of automated vehicles in the scenario but is always far from reaching the maximum possible length (eight). In fact, the majority of platoons have less than eight vehicles independently of the rate of automated vehicles in the scenario. Even if all vehicles are automated, Fig. 2 shows that less than 40% of the platoons are made up of eight vehicles. Despite the variations observed in Fig. 2, the impact of platooning maneuvers on the traffic flow and speed (Fig. 1) does not vary largely with the percentage of automated vehicles in the scenario. On the other hand, the values of the traffic flow and speed are significantly influenced by the percentage of automated vehicles in the scenario. The impact on traffic of the length of platoons seems hence to be less important than other parameters like the percentage of automated vehicles. In any case, it is still an open question what is the optimum platoon length when taking into account the platooning maneuvers and their impact on traffic.

VI. CONCLUSION

This study has analyzed for the first time the impact of platooning maneuvers on the traffic flow and speed in mixed traffic scenarios where automated and non-automated vehicles coexist. The study has been conducted using the open-source platooning simulator PERMIT developed by the authors and openly released to the community [5]. The obtained results demonstrate that platooning maneuvers have a relevant impact on the traffic flow and speed, and that studies that do not take into account platooning maneuvers overestimate the traffic benefits provided by platoons. The impact is higher with lower penetration rates of platooning since more conventional vehicles can interfere with the execution of platooning maneuvers, and the length of platoons is reduced.

---

[4] Average across all percentages of automated vehicles.

[5] Higher gains were reported in [2] when the length augments from 2 to 4 vehicles than from 4 to 8 vehicles.

REFERENCES

[1] M. Michaelian and F. Browand, “Field experiments demonstrate fuel savings for close-following”, California PATH, Research report UCB-ITS-PRR-2000-14, 2000.

[2] L. Terruzzi, R. Colombo, and M. Segata, “On the Effects of Cooperative Platooning on Traffic Shock Waves”, *Proc. IEEE VNC*, Torino, Italy, 2017, pp. 37–38.

[3] M. Amoozadeh, H. Deng, C.-N. Chuah, H. M. Zhang and D. Ghosal, “Platoon management with cooperative adaptive cruise control enabled by VANET,” *Vehicular Communications*, vol. 2, no. 2, pp. 110-123, 2015.

[4] Q. Deng, "A general simulation framework for modeling and analysis of heavy-duty vehicle platooning," *IEEE Trans. Intell. Trans. Syst.*, vol. 17, no. 11, pp. 3252-3262, 2016.

[5] J. Mena-Oreja and J. Gozalvez, “PERMIT – A SUMO simulator for platooning maneuvers in mixed traffic scenarios,” *presented at the Proc. IEEE ITSC*, Maui, HI, USA, 2018.

[6] S. E. Shladover, D. Su and X.-Y. Lu, “Impacts of cooperative adaptive cruise control on freeway traffic flow*,” Transportation Research Record: Journal of the Transportation Research Board*, no. 2324, pp. 63-70, 2012.

[7] B. van Arem, C. van Driel, and R. Visser, “The impact of cooperative adaptive cruise control on traffic-flow characteristics,” *IEEE Trans. Intell. Trans. Syst.*, vol. 7, no. 4, pp. 429–436, 2006.

[8] A. Talebpour and H. S. Mahmassani, “Influence of connected and autonomous vehicles on traffic flow stability and throughput,” *Transportation Research Part C: Emerging Technologies*, vol. 71, pp. 143-163, 2016.

[9] N. Harwood and N. Reed, "Modelling the impact of platooning on motorway capacity," *Proc. Road Transport Information and Control Conference*, London, UK, 2014, pp. 1-6.

[10] D. Krajzewicz, J. Erdmann, M. Behrisch and L. Bieker, “Recent Development and Applications of SUMO - Simulation of Urban Mobility,” *International Journal On Advances in Systems and Measurements*, vol.5, no. 3&4, pp. 128-138, 2012.

[11] M. Segata, S. Joerer, B. Bloessl, C. Sommer, F. Dressler and R. Lo Cigno, "PLEXE: A platooning extension for Veins," *Proc. IEEE VNC*, Paderborn, Germany, 2014, pp. 53-60.

[12] E. Semsar-kazerooni and J. Ploeg, “Interaction protocols for cooperative merging and lane reduction scenarios,” *Proc. IEEE ITSC*, Las Palmas, Spain, 2015, pp. 1964-1970.

[13] S. Krauß, *Microscopic modelling of traffic flow: Investigation of collision free vehicle dynamics*, Ph.D. dissertation, Univ. of Cologne, Cologne, Germany, 1998.

[14] J. Erdmann, “SUMO’s lane-changing model,” *Lecture Notes in Control and Information Sciences. 2nd SUMO User Conference*, Berlin, Germany, 2015, Springer International Publishing, 2015, pp. 105-123.

[15] R. Rajamani, *Vehicle Dynamics and Control*, 2nd ed., Springer, 2012.