Study of CO_2 Emissions in Platoon Driving

Cornel Constantin[1], Cristian-Alexandru Rențea[2(✉)], Marius-Valentin Bățăuș[2], and Gheorghe Frățilă[2]

[1] Faculty of Transports, University Politehnica of Bucharest, 313 Spl. Independentei, Bucharest, Romania

[2] Automotive Engineering Department, University Politehnica of Bucharest, 313 Spl. Independentei, Bucharest, Romania

rentea.cristian@yahoo.com

Abstract. Modern cars now have more intelligent systems than never before. Advanced driver-assistance systems (ADAS) and vehicle-to-vehicle (V2V) communication's which improve the safety and driving comfort can also be used to decrease fuel consumption and emission. One potential use of these technologies is to facilitate platoon driving of several vehicles, especially on highways. This paper aims to investigate the level of CO_2 emissions for a platoon with different configurations. Using a validated detailed model created in LMS Imagine.Lab AMESim, an industrial modelling and simulation environment, the CO_2 emissions of a platoon made of up to seven sedan vehicles were calculated. The results were calculated for several stabilized speeds and also a standardized high-speed cycle. A reduction of up to 18% in CO_2 emissions was obtained depending on the traveling speed and number of vehicles in the platoon.

Keywords: Platoon · CO_2 emissions · ADAS

1 Introduction

In the race to increase driving safety and comfort, many automotive companies have made one of their main priorities the introduction of autonomous driving. This is now possible thanks to the improvements in the advanced driver-assistance systems (ADAS) and vehicle-to-vehicle (V2V) communication's which can alleviate the stress of driving by taking over some of the driver responsibilities but also take pre-emptive measures by knowing the vehicle surroundings and the other traffic participants intentions and actions.

These technologies can also be used to reduce the energy consumption of the vehicles. The increased flow of information between traffic participants in conjunction with the driver assistance systems can now facilitate platoon driving as a mean to reduce fuel consumption. By knowing what the vehicle in front intends to do, the following vehicles can make predictive actions in order to keep unnecessary braking and acceleration to a minimum thus uniformizing the traveling speed and to maintain a short distance between vehicles to decrease the air drag coefficient. These actions are most efficient at high vehicle speeds, therefore platoon driving has the best use case in highway driving.

I. Dumitru et al. (Eds.): ICOME 2022, AHE 15, pp. 248–254, 2023.
https://doi.org/10.2991/978-94-6463-152-4_28

The influence of platoon driving on the drag coefficient was studied in the past with experiments on real vehicles [1], on models in wind test tunnels [2, 3] but also by the mean of computational fluid dynamics (CFD) simulations [4, 5]. Because platooning's main advantage is the decrease in the drag coefficient many studies were concentrated on trucks [6, 7] since they will benefit the most from it. Studies were also made on passenger cars in different configurations from 2 and up to 7 vehicles in a platoon, with the distance between the vehicles varying from 1m to one vehicle length.

With the new Corporate Average Fuel Economy (CAFE) regulations the automotive industry is under pressure to produce cleaner vehicles which under today's standards involves a certain degree of electrification. Since electric vehicles raise their own set of issues like battery capacity and price, charging infrastructure, etc., it's safe to say that, for the time being, vehicles equipped with conventional propulsion systems or some degree of hybridization are here to stay. For these there is still a great potential in the reduction of CO_2 emissions through conventional methods. In [8] a reduction of up to 18% (SUV) or 20% (C-class) in the CO_2 emissions was demonstrated using available technologies.

This paper investigates the additional potential CO_2 emissions reduction that can be achieved thru platoon driving at stabilized high speed and also on the Highway Fuel Economy Cycle (HWFET). The improvement of vehicle velocity profile is also evaluated by considering the vehicles speed variations in an uncoordinated convoy. The study was done for a C class sedan vehicle by dynamic modelling and simulation using a validated model presented in [9] developed using LMS Imagine.Lab AMESim, an industrial modelling and simulation environment.

2 Vehicle Behaviour in Convoys

The evolution of the vehicle velocity profile in a convoy of vehicles can be observed using a leader-follower model. There are numerous theoretical models of the driver based on different methods: differential equations, conditional constructs, algorithmic, fuzzy logic, neuronal networks [10]. A diagram of the driver-vehicle system for the front vehicle tracking is presented in Fig. 1.

Starting from the vehicle equation of rectilinear motion the following equation can be deduced [10].

$$\dot{v}_{i+1} = k \cdot \left[v_i(t-T) - v_{i+1}(t-T)\right] \tag{1}$$

where: v_i is the velocity of the vehicle in front; v_{i+1} is the velocity of the vehicle in rear; t is the current time, T is the driver reaction time and k is a constant.

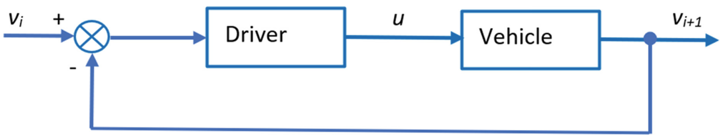

Fig. 1. Diagram of the driver-vehicle system for the front vehicle tracking.

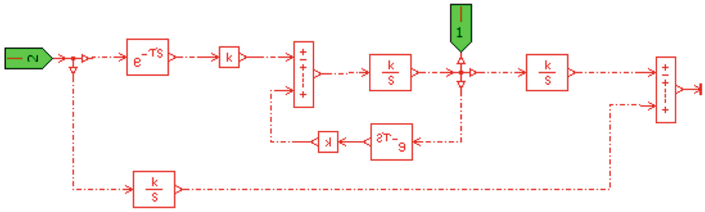

Fig. 2. Linear model for leader-follower for a single vehicle.

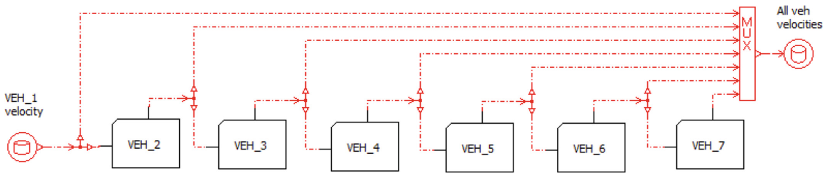

Fig. 3. Leader-follower model for a convoy of 7 vehicles.

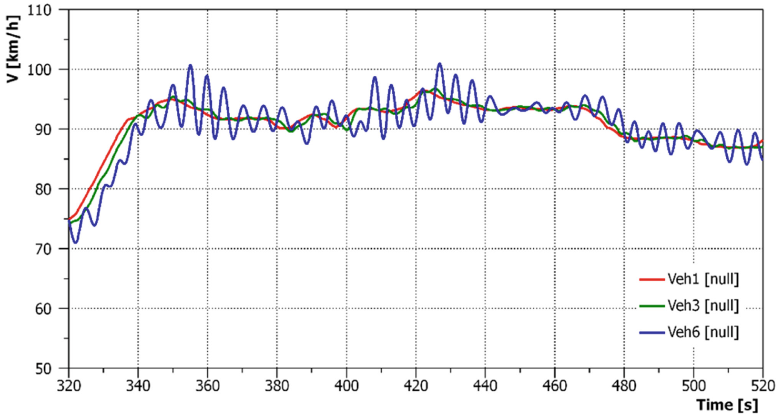

Fig. 4. The speed variation of vehicles 1, 3 and 6 from the uncoordinated convoy.

The numerical integration of the Eq. (1) is done using the Signal & Control Library from AMESim as shown in Fig. 2.

Starting from the first vehicle, by successive integrations (Fig. 3) is possible to obtain the vehicle velocity profiles of a non-platoon vehicle convoy.

The evolution of some of the velocity profiles for a non-platoon vehicle convoy are shown in Fig. 4.

3 Results

The study is done for a C class sedan vehicle by dynamic modelling and simulation using a validated model presented in [9] developed using LMS Imagine.Lab AMESim, an industrial modelling and simulation environment.

Table 1. CO_2 emissions for stabilized speed.

No. of vehicles	Average CO_2 emissions [g/km]			Improvement over the isolated vehicle [%]			
	70 km/h	100 km/h	130 km/h	70 km/h	100 km/h	130 km/h	C_d
1	83.8	110.7	163.7	0	0	0	0
2	80.9	104.5	152.8	3.5	5.6	6.7	8.8
3	76.8	96.0	137.8	8.3	13.3	15.8	20.6
4	77.1	96.8	139.1	7.9	12.6	15.0	19.5
5	76.9	96.2	138.2	8.2	13.0	15.6	20.2
7	75.6	93.4	133.1	9.8	15.7	18.7	24.2

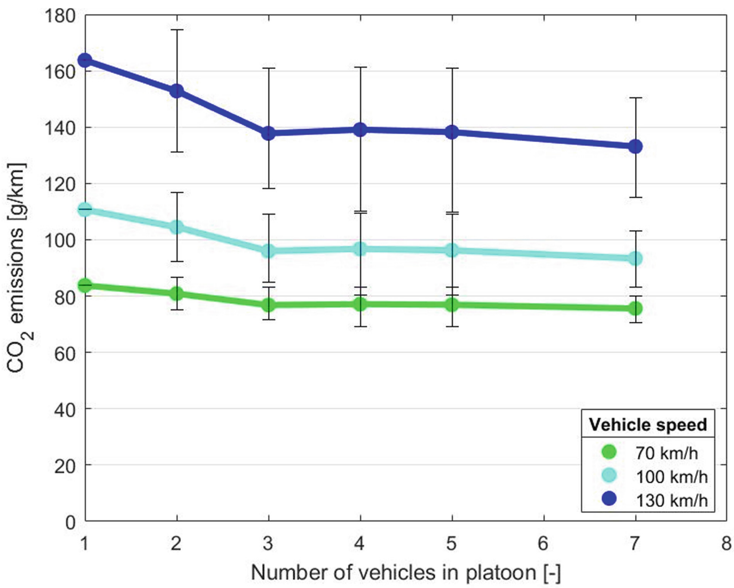

Fig. 5. CO_2 emissions reduction for platoon driving at high stabilized speed.

The simulations were done for a single vehicle and for short spacing (1 m inter-vehicle distance) platoons consisting of 2, 3, 4, 5 and 7 identical passenger vehicles. The variation of the drag coefficient (C_d) is taken from [4] and applied for the studied application.

Three constant vehicle velocities were considered for the simulations: 70 km/h, 100 km/h and 130 km/h. The results are shown in Table 1 and Fig. 5.

Figure 5 shows also the variation interval of CO_2 emissions between a given platoon vehicles in each case.

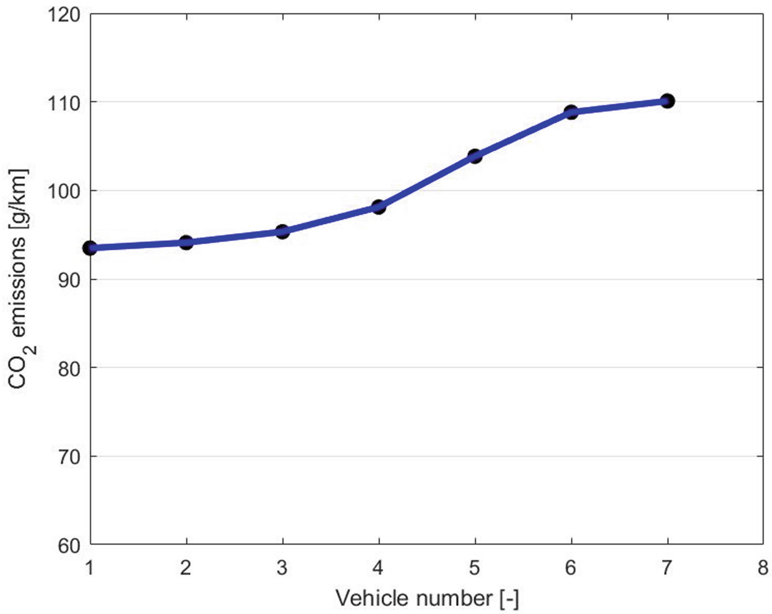

Fig. 6. CO_2 emissions for uncoordinated high traffic density driving.

As observed in Table 1, a simple comparison using the mean drag coefficient is insufficient for a conclusion on CO_2 emissions reduction. This is due to the different relative magnitude of aerodynamic drag at different speeds and of change in the load applied on the engine.

Also, it's worth mentioning that there is a large difference between the first vehicle in the platoon which has the most benefit (up to 33% compared to a single isolated vehicle at 130 km/h) and the last vehicle, which only achieves 8.2% reduction in CO_2 emissions compared to the same reference. Also, as stated in [3], design features optimised for isolated vehicles can have negative effects on the performance of the platoon, so positioning a vehicle in the platoon must be carefully done so that the efficiency of the platoon is increased while having as many vehicles benefit from it.

For the standardized high-speed cycle (HWFET) the CO_2 emissions for the isolated vehicle and for a non-platoon vehicle convoy are considered for an accurate comparison. The HWFET cycle is a driving schedule, developed by the U.S. EPA (Environmental Protection Agency) for the determination of fuel economy of light duty vehicles and has a mean speed of 78.2 km/h with a vehicle speed fluctuation of 19.2%.

In Fig. 6 the CO_2 emissions for every vehicle in a non-platoon vehicle convoy is shown and is used to compute the average CO_2 emission for convoys of 2 to 7 vehicles needed for the comparison in Table 2 and Fig. 7.

As observed in Table 2, is important to consider the influence of speed variation in the convoy for a variable speed cycle to obtain a more realistic average CO_2 emissions. This influence can reach over 1/3 of the improvement for a seven vehicles platoon.

Table 2. CO_2 emissions for HWFET cycle.

No. of vehicles	Average CO_2 emissions [g/km]		Improvement [%] over	
	Platoon	Uncoordinated convoy	Isolated vehicle	Uncoordinated convoy
1	93.5	93.5	0	0
2	89.6	93.8	4.2	4.5
3	84.3	94.3	9.8	10.6
4	84.8	95.3	9.3	11.0
5	84.5	97.0	9.6	12.9
7	82.4	100.5	11.9	18.1

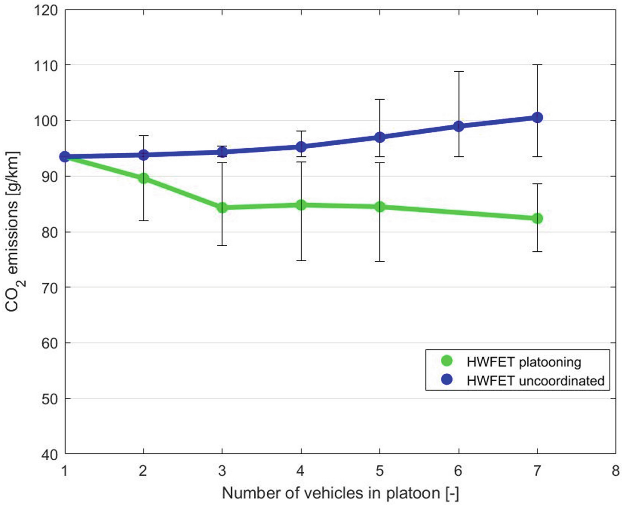

Fig. 7. CO_2 emissions reduction for platoon driving in HWFET cycle.

4 Conclusions

It was demonstrated that a simple comparison using the mean drag coefficient is insufficient for a conclusion on CO_2 emissions reduction and the improvement is highly dependent on number of vehicles and the platoon speed. For the studied application the improvement starts from 3.5% for 2 vehicles at 70 km/h and reach 18.7% for 7 vehicles at 130 km/h.

For a variable speed cycle is important to consider the influence of speed variation in the convoy to obtain a more realistic average CO_2 emission. This influence can reach over 1/3 of the improvement for a seven vehicles platoon.

The use of platoon of vehicles is problematic in terms of the gain difference between them, usually the front vehicle is favourited and the last has the lowest gain (35% difference between them calculated in relation to the platoon average for a vehicle speed of 130 km/h). This can be mitigated through variable road taxes or dynamically choosing the position in the platoon based on the history of driving.

The use of short-spacing platoons of three vehicles is very efficient in terms of aerodynamics but is important that such platoons to coordinate each other for maximum CO_2 emissions reduction by means of vehicle speeds uniformization.

References

1. Mark Michaellan, Fred Browand: Quantifying Platoon Fuel Savings: 1999 Field Experiments, University of Southern California (1999).
2. Michael Zabat, Nick Stabile, Stefano Frascaroli, Frederick Browand: The Aerodynamic Performance of Platoons: Final Report, California PATH Research Report UCB-ITS-PRR-95–35 (1995).
3. Hesham Ebrahim, Robert Dominy: Wake and surface pressure analysis of vehicles in platoon. Journal of Wind Engineering & Industrial Aerodynamics (2020).
4. Sai Teja Kaluva, Aditya Pathak, Aybike Ongel: Aerodynamic Drag Analysis of Autonomous Electric Vehicle Platoons (2020).
5. Renata Gnatowska, Marcin Sosnowski: The influence of distance between vehicles in platoon on aerodynamic parameters. The European Physical Journal Conferences (2017).
6. Vasudev Vohra, Rui Ni, Mohamed Wahba, Sean Brennan, Gökhan Akarslan: An examination of vehicle spacing to reduce aerodynamic drag in truck platoons (2017).
7. Venkatasubramanian Viswanathan, Varun Shankar, Shashank Sripad: Platooning for Improved Safety and Efficiency of Semi-trucks (2021).
8. Cornel Constantin, Marius Băţăus, Cristian Renţea, Gheorghe Frăţilă: Effectiveness of the measures for CO_2 emission reduction in real world. In IOP Conference Series: Materials Science and Engineering (Vol. 1220, No. 1, p. 012015). IOP Publishing (2022).
9. Cristian Rențea, Gheorghe Frățilă: The modelling and simulation of propulsion systems to estimate CO_2 emissions. Romanian Journal of Automotive Engineering, vol. 27, no. 1 (2021).
10. Aurel P. Stoicescu: Proiectarea performanţelor de tracţiune şi de consum ale autovehiculelor, Editura Tehnică, Bucureşti, (2007).