

TRUCK PLATOONING: EXPECTED BENEFITS AND IMPLEMENTATION CONDITIONS ON HIGHWAYS



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Abstract

Heavy vehicle platooning is a concept derived from the railway sector. Vehicles travel at short or very short spacing, with an electronic coupling system avoiding the human reaction time. It is an automated road system with connected vehicles. The main challenges are a cut off of aerodynamic forces and thus fuel saving, an increase of lane capacity with less congestion and shorter travel times, reducing GNG emissions, an improving drivers' efficiency through less stress and longer working time. Road safety may also be improved thanks to the automation. Long distance freight transport can benefit of flow optimization. Road authorities and operators are expecting a better use of the existing infrastructure and the development of a new business model. The European Truck Platooning Challenge (ETPC) proposes a long term vision and the H2020 project ENSEMBLE launched in June 2018 offers a unique opportunity to the truck industry to implement large scale tests in the EU Member States and to research organisations to investigate the benefits and potential drawbacks to be mitigated.

Keywords: Heavy good vehicles, platoon, truck platooning, road infrastructure, freight transport, transport efficiency.

1. Stakes, Objectives and State-of-the-Art

Platooning consists of grouping vehicles into sequences reducing interdistances to increase road capacity and reduce aerodynamic effects. Platoon driving requires a higher degree of automation as spacing is shorter. The electronic coupling of the vehicles allows them to accelerate or brake simultaneously by eliminating human reaction times. The lateral and longitudinal guidance of the vehicles is also automated in a platoon.

The stakes for heavy goods vehicles are high, in terms of energy efficiency, infrastructure capacity, road safety and productivity of road freight transport (Alam et al., 2015). The reduction in aerodynamic forces allows fuel savings of up to 5-10%. The increase in the lane occupancy rate where platooning takes place makes it possible to increase the capacity and thus to reduce congestion and travel times during peak periods, as well as pollution due to emissions and consumption of vehicles in traffic jams. In a platoon, the drivers' demand is reduced because they do not "drive", except the leading vehicle's driver. This makes possible to envisage a possible lengthening of the working times at constant load, thus a better productivity of the drivers. Finally, automation eliminates human errors, the main causes of traffic accidents – 90% of the accidents result of a human error -, and paves the way for an improvement in road safety by reducing front to rear collisions, lane departures, or rollovers and knifejackings of heavy good vehicles. Economic and environmental benefits are expected for road freight transport.

Road freight accounts for more than 75% of trade in goods within the European Union and is thus of considerable economic importance for the growth of Member States and for the competitiveness and development of enterprises. Medium and long-distance freight transport on motorways and main highways, affected by platooning, could benefit from an optimization of traffic flows and management on existing infrastructure. The road Directors of the Member States (CEDR) envisage the possibility of optimizing the use of infrastructure, that it is no longer possible to increase significantly, and of moving towards a new business model of transport.

The concept of platooning, closely related to driving and vehicle automation, belongs to the Automated Highway System (AHS) or Smart Road within the ITS (Intelligent Transport System) framework. In 1997, the National Automated Highway System Consortium (NAHSC) project was launched in California to create an automated road prototype in San Diego on Interstate 15 (AHS, 1996-97). The technology tools and sensors were installed on board of vehicles to read road markings, complemented with radars and V2V communication devices for autonomous driving. These works resulted in trajectory and cruise control systems.

The series of European projects CHAUFFEUR started in 1996 and enabled the development of electronic coupling of heavy goods vehicles at short distance. They demonstrated their technical feasibility, economic viability and operational acceptability (Fritz et al., 2004). They were followed in 2002-2004 by the French project Automated Road for Heavy Good Vehicles (LCPC, LIVIC, INRETS, 2004). Nevertheless, greater operational flexibility was required to make the concept of platooning effective. The German KONVOI project (2005-2009) (Kunze et al., 2009) and the Swedish iQFleet project (Bergenheim et al., 2012a) aimed to produce and evaluate electronically assisted heavy good vehicles' convoys on open roads with fully automated longitudinal and lateral control. The SARTRE European project (Safe Road Trains for the Environment, 2009-2012) developed strategies and technologies for the management of open road platoons, with all types of vehicles, cars and heavy good vehicles (Bergenheim et al., 2012b). Experimentations were carried out on the Volvo test track near Gothenburg in Sweden and in Spain near Barcelone in 2012.

The FHWA funded two research projects in 2013 on truck platooning, with partly automated driving. Auburn University and the American Trucking Association (Bishop et al., 2014) carried out the first one, and the DoT of California, Berkeley University and Volvo Trucks in the frame of the PATH (Partners for Advanced Transportation Technology) project did the second one, including a test on the corridor I-710. Test track and road experimentations were carried out in a Japanese project (ITS Energy) in 2008 (Tsugawa, 2014).

The European project COMPANION (2013–2016) studied truck platoon development and management, taking into account other road users’ acceptability, economic, legal and standardization issues (Companion, 2016).

2. Platooning Technologies

Platooning uses various devices for longitudinal and lateral trajectory control (Rajaman et al., 2000), and to keep the platoon in operational and safety conditions: radars and lidars (lasers), global positioning systems (GPS), and V2V secured communications (Bergenheim et al., 2012b).

When manually driving, the safety spacing between trucks is 50 m in Europe (100 m in tunnels), and 200 ft (60 m) in North America, to account for time of perception and reaction by the drivers in case of emergency braking of the preceding vehicle. This safety spacing includes the distance traveled during the perception and reaction times, i.e. 25 m at 90 km/h, and a difference of 11 m/s² between the slowing down rates of the first and the second truck. This should not be confused with the stopping distance, which is app. 70 m on a dry road for a slowing down rate of -7 m/s², which begins after 1 s, while the stopping distance alone is 45 m. With a cruise control by radar or lidar, which automatically launch the braking, the perception time is avoided and only the distance due to the difference of slowing down rates remains. With connected vehicles in platoon, the braking of the following vehicles starts simultaneously and with the same intensity than the leading vehicle, thus the safety spacing may be reduced to 5 or 10 m, to account for the differences between the braking capacities of the vehicles (load, tires, brakes...). Figure 1 shows these 3 cases. Vehicles are equipped with braking and accelerating systems enslaved to the leading vehicle, which keep spacing and avoid collision as a cruise control system (Figure 2).

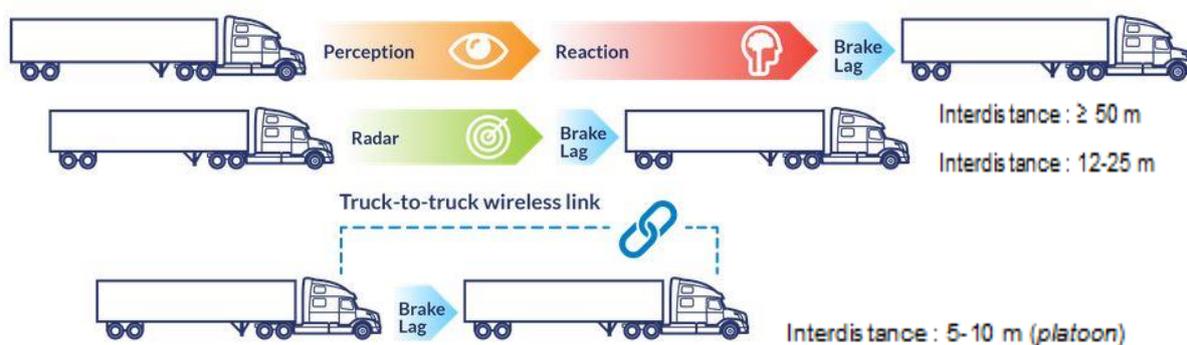


Figure 1 – Cruise control and safety spacing

Lateral control in platoon must also be automated, because of the lack of visibility of the following vehicles’ drivers (Figure 2). Lateral guidance uses cameras reading road marking. However, this principle is not fully reliable because of local defaults, or a loss of visibility under rain, snow or dust. Thus, the system must assess the road marking’s visibility and give back the driving responsibility to the drivers if the safety conditions are not guaranteed. A

global positioning by differential GPS (accuracy of 0.05 to 0.10 m) may also be used (Figure 2). More sophisticated technologies developed for cars (Papadimitriou and Tomizuka, 2004), and still at a pre-prototype stage for trucks, use optical sensors and accelerometers to monitor the trajectories of the preceding and considered vehicles, to enslave the following vehicles trajectories to the leading vehicle with a dynamics model. Dedicated short-range communication (DSRC) at 5.9 GHz and Wifi IEEE 802.11p (Figure 2), connect trucks of a platoon to synchronize braking and harmonize the engine torques, or to activate the protocol allowing a single vehicle to join or leave a platoon. Platoons may be formed or released on the fly in the traffic flow. On board cameras eliminate dead angles and provide to the drivers contextual information for maneuvers such as leaving the platoon. Cameras coupled to lateral radars help anticipating and helping other vehicle inserting in the platoon if needed.

V2I long-range communication through a network or the cloud and cellular transmission or Wifi (Figure 2), provide a whole platoon management system by a control center. That includes platoon forming by grouping several vehicles, and business transactions to share the platooning gains between the parties.

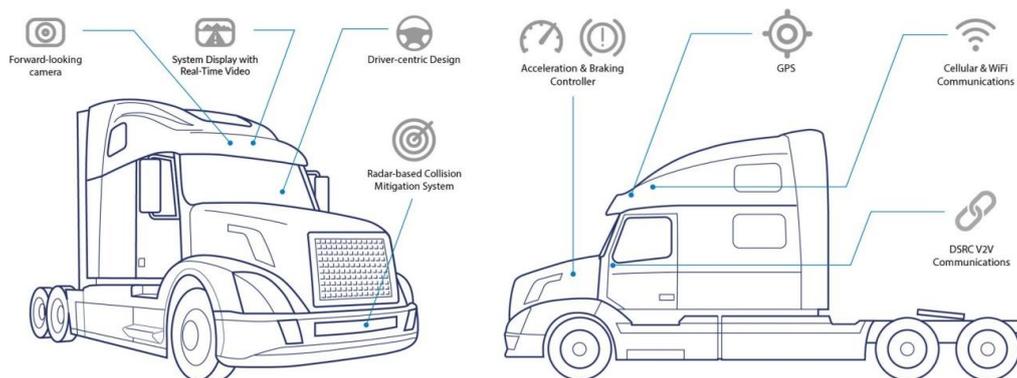


Figure 2 – Platooning technologies (Peloton, <http://peloton-tech.com>).

3. Expected Benefits of Truck Platooning

3.1 Aerodynamic Gains and Energy Savings

Platooning reduces truck spacing, and thus aerodynamic push and drag forces, which refrain the vehicle moving forwards. These forces induce app. 40% of the energy consumption of a standard 40 t articulated 5-axle combination (Figure 3). Fuel cost reaches app. one third of the operation cost of a truck in Europe, thus 12 to 15% of this cost is induced by the aerodynamics.

The Californian PATH programme showed in the early 2000s that fuel savings up to 8 to 11% are achievable for truck spacing of 3 to 10 m and velocities of 80 to 90 km/h (Browand et al., 2004). More accurately, with 10 m spacing, gains of 6% and 10% were assessed respectively for the leading and following vehicles. With shorter spacing between 3 and 10 m, gains reached respectively 5 to 10% and 10 to 12%, but with empty trailers. Below 8 to 10 m, gains are less. Alam et al. (2010) reported gains of 4.7 to 7.7% depending on the spacing with 5-axle articulated and 40 t European combinations at 70 km/h. For three such combinations in a platoon at 10 m spacing and 80 km/h, modelling and test track experimentation showed average gains of 14%, i.e. 7.5% for the leading vehicle and 16% for the following vehicles (Tsugawa et al., 2011). The German KONVOI project showed similar results as well as the New Energy and Industrial Technology Development Organization (NEDO) in Japan. An

experimental investigation carried out in the US, by the National Renewable Energy Laboratory (NREL), with two articulated trucks on a test track in Texas, assessed platooning gains in various conditions (Lammert et al., 2014). Tests done at velocities between 85 and 115 km/h, spacing from 7 to 25 m and masses from 29.5 to 35.2 t showed gains for the leading vehicle up to 2.7 to 5.3% depending on the spacing, while the following vehicles gained 2.8 to 9.7%. Disconnecting the cooling ventilator, gains reached 8.4 to 9.7%. However, without cooling, spacing should be increased in hot weather conditions.

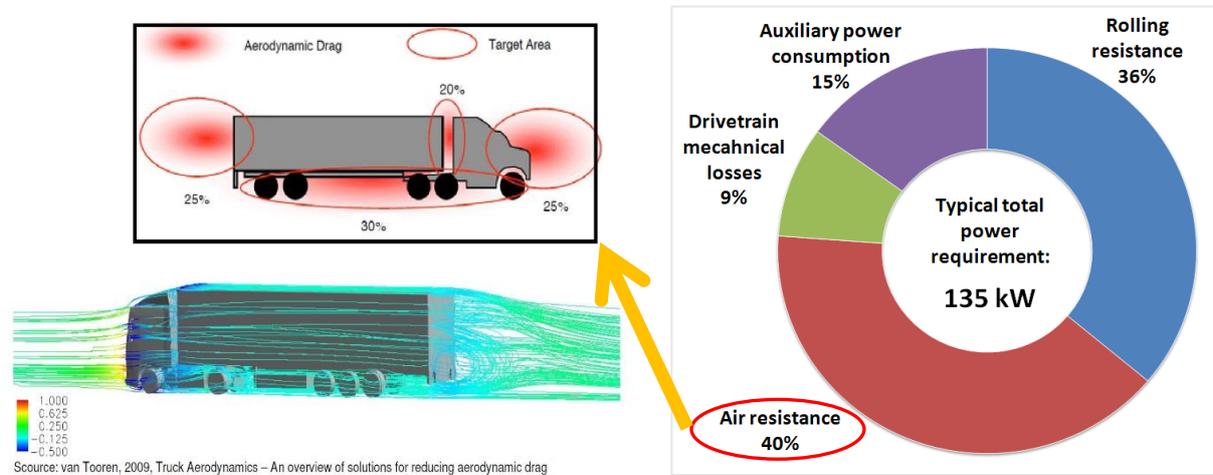


Figure 3 – Share of the aerodynamic forces in the truck energy consumption.

For platoons with more than two trucks, gains are the highest for the vehicles in the middle of the platoon, and less for the leading and last vehicles. The PATH program showed that an optimal platoon configuration consists of putting the most aerodynamically performant vehicle in front and the less performant at the back. Implementing platoons involving different vehicle owners in real conditions requires compensation mechanisms. They may be based either on switching the vehicle rows in the platoon along the journey, or on setting a payback per kilometer by the middle vehicles to the leading and rear vehicles. Several authors, above all in CHAUFFEUR projects, noticed that the gains (in percentages) decreased when the truck mass increased, because of the rolling resistance which is of the same magnitude than the aerodynamic resistance (Figure 3). Other energy savings remain to investigate. In a platoon, velocities are stable and uniform, with identical braking and accelerations for all the trucks. Braking is also better anticipated, which avoid over consumption and stop and go flows.

3.2 Infrastructure Efficiency Improvement

Platooning also increases the capacity and flow of existing traffic lanes (Michael et al., 1998). Reducing vehicle spacing increases the occupancy rate, and thus the flow for a given mean velocity. However, there are various traffic configurations:

- (1) Congestion (stop and go), where the occupancy rate is already saturated and thus the platooning is not efficient.
- (2) Free traffic, when the demand does not exceed the lane capacity, the platooning is not necessary, but for aerodynamic reasons and fuel savings.
- (3) Close to the lane capacity limit, the successive vehicles start being in interaction, inducing stop and go traffic and abrupt changes of velocity. Thus, the platooning may increase the lane

capacity and thus push away the disturbances leading to a flow drop down and an increase of the fuel consumption.

The lane capacity C (in veh/hr) is a function of the mean spacing D between vehicles and of the mean velocity V : $C = V/D$. Platooning tends to increase the capacity by reducing the spacing D at constant velocity V . However, to allow safe platooning, vehicles should be equipped with a V2V communication system and performant braking capacities. Thus, all the trucks in a platoon behave in coherence and predictable manner, avoiding the risks of manual driving and of driver behavior. E.g. at 90 km/h (25 m/s), a time interval of 2 seconds between trucks is equivalent to the regulatory spacing of 50 m. With standard 5-axle articulated European trucks of 16.5 m in length, the occupancy rate is 15 trucks/km, or a flow of 1 350 trucks/hr. Assuming that 3 trucks travel at 10 m spacing in a platoon, it covers a lane length of 69.5 m. With a 2-second interval between such platoons, the whole occupancy rate jumps to 25 trucks/km, and the mean flow reaches 2 250 trucks/hr, i.e. a 67% capacity gain. With the same mean velocity of 90 km/h and a truck spacing of 8 m in the platoons, the lane capacity increases by 90% for 4 truck platoons, and by more than 100% for 5 truck platoons. Figure 4 gives results of a report by the Canadian National Research Center (CNRC), for 23 m long combinations, theoretical speeds up to 144 km/h and platoons with up to 10 vehicles, assuming a 2-second interval between platoons.



Figure 4 – Theoretical lane capacity increase with mean velocity and platoon length (Gaudet, 2016).

Obviously these flows are the theoretical maxima, not reached in practice. Nevertheless these estimates show that platooning open the way towards significant lane capacity increases on motorways and highways, up to 50 to 100%. The saturation threshold may thus be pushed away, avoiding some congestions and stop and go traffic situations. Journey time savings and GNG emission cut-off on the busiest highways are expected.

3.3 Driver Efficiency and Truck Range Increases

A major gain of platooning results of the significant truck range increase. A study carried out by the TNO (Dutch research institute) showed that this gain might reach up to 2/3 of all the gains of platooning, while the aerodynamic and the logistics gains are both quoted at 1/6. Medical and behavioral studies on the driving tasks, drivers' vigilance, stress and fatigue were carried out. They suggested that the driving load and fatigue is the same for a driving sequence of 4.5 hours than for two successive sequences: one of driving during 3 hours and

one of monitoring the automatic driving (level 3 or 4 of automation) in a following truck traveling in a platoon during three hours. If two drivers travel in a 2-truck platoon, the current allowed maximum driving time is 4.5 hours + 4.5 hours with a rest time of 45 minutes in the middle. It was suggested to substitute that by two sequences of 6 hours, each including 3 hours of driving as a leader and 3 hours of monitoring as a follower, and the same rest time of 45 minutes in the middle (Figure 5). Thus, by switching twice the vehicle order in the platoon, the traveling time of both trucks increases from 9 hours to 12 hours within the same day, which leads to a range increase of 30%, from 720 to 950 km for an average velocity of 80 km/h on motorways and highways. This scenario is less demanding for the drivers and more efficient.

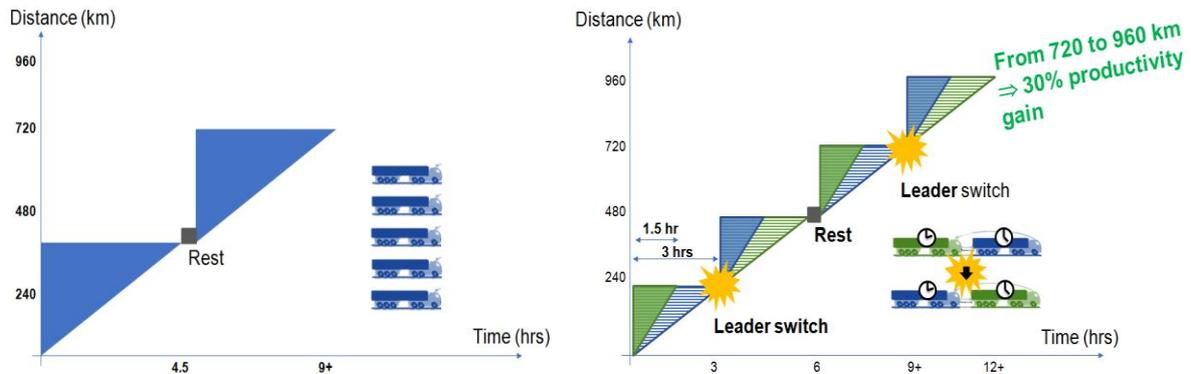


Figure 5 – Driving time and truck range increases by platooning (TNO).

For container delivery or freight arriving in Europe through Rotterdam harbor, the TNO proved that the number of consumers reached within 12 hours was increased from 150 millions to 250 millions inhabitants (Figure 6), with a potential economic gain of 3 to 35 billions euros depending on various scenarios. Moreover, the number of return journeys achievable within a day would be increased by more than 50%.



Figure 6 – Benefit of range extension by platooning (TNO).

The driver productivity gain should be shared among various beneficiaries: consumers, transport companies, and drivers. The driver tasks would deeply evolve, the drivers being more qualified with additional training, and their salaries could be increased.

The potential road safety gains are not addressed in this paper, but may also be significant thanks to the automation, the velocity smoothing, and the driver stress reduction. In addition it should be noted that in many European Union (EU) Member States the regulatory truck spacing on motorways and highways is not respected, and wild platoons are traveling without any driving assistance, nor rules. The potential logistics gains are also not addressed here, but automation and loading / unloading pooling in logistics centers could be beneficial.

4. Conditions and Limitations of Truck Platooning Implementation

4.1 Road Safety and Operation

Indeed platoons will only circulate on motorways and highways with at least 2 x 2 lanes and separate carriageway. On bidirectional roads, platoon overtaking would be an issue, as well as visual and crossing inconvenience in presence of a platoon. However, on highways and motorways, with at least two lanes per direction, the overtaking maneuvers would remain comfortable and safe. Assuming that a platoon of 6 trucks (quite long) is traveling on the slow lane at the maximum velocity of 90 km/h, with a spacing of 10 m, which make a total platoon length of 149 m. and individual truck lengths of 16.5 m. For a car travelling at 130 km/h (max. speed on a motorway in France), the velocity difference with the platoon is 40 km/h, thus the time to overtake, assuming a margin of 2 seconds before and after the manoeuvre to change the lane, is: $T = 4 + (149 * 3.6) / 40 = 17.41$ s. Which means that the total distance of overtaking is 629 m. If the car is travelling at 120 km/h, the distance increase is up to 790 m. These distances are not much longer than the distance currently used for overtaking a single truck on a highway.

While traveling, platoons should be well marked with clear information about their length, to facilitate anticipated maneuvers of the other road users. That is very important at night or in low visibility conditions when the distance assessment becomes more difficult. In some circumstances such as foggy, snow or ice conditions, platooning could be suspended.

In hilly zones, platooning requires enhanced and harmonized powered truck engines, to avoid speed discrepancies in uphill slopes. Another suggested provision to ensure a safe emergency braking, consists of assessing the tire and braking performances of each truck in a platoon. If some significant differences are found, the most performant truck (for braking) must be at the rear of the platoon to avoid any risk of rear-front collision. Tire manufacturers and OEMs could provide on-board devices to continuously monitor these braking performance, depending on the pavement conditions (dry, wet, friction coefficient), and to advise the driver on the best (safest) rank in the platoon.

Platooning only makes sense on highly trafficked itineraries. When the platooning conditions are not satisfied, in some specific road sections, the trucks will need to recover the current regulatory spacing, such as in highway and motorway interchanges, or while approaching entrances and exits, to avoid discomfort of other road users. A dedicated road signing, both by physical road signs and electronic messages displayed on the equipped for platooning trucks, will have to be deployed by the road operators to regulate the platoon operation.

Platoons should be formed on the fly and on request. That will need communication protocols and permits allowing joining or leaving a platoon. These permits would be delivered in real time and remotely, from management and checking centers monitoring the platoons in operation and informing the drivers before they join an existing platoon or they create a new platoon. Charging platooning vehicles is also an issue for tariff equalization between transport

companies and truck owners, depending on their row in a platoon. That will required some adapted EU legislation.

4.2 Impact on Infrastructure

Platoons of very heavy vehicles should also be banned crossing long span bridges, above all if the loading capacity is limited because of a poor or old design, or of fatigue or other damages. Longer the span length (and shorter the spacing), higher the number of trucks acting simultaneously on the bridge deck, as shown for single simple supported span bridge (Figure 7). The simple supported span bending moment at mid-span induced by one platoon crossing the span increases with the platoon and span length, and decreases with the truck spacing (Figure 8). The total load and thus the induced load effects should be monitored and kept below some given thresholds. Weigh-in-motion (WIM) devices may be used to measure the individual axle loads and gross vehicle weights in a platoon, a few kilometer upstream of a bridge, to assess the potential load effects on the most sensitive parts of the bridge, and to decide if the platoon is allowed crossing the bridge. A message (on a variable message sign or an on-board message) could be sent to release the platoon.

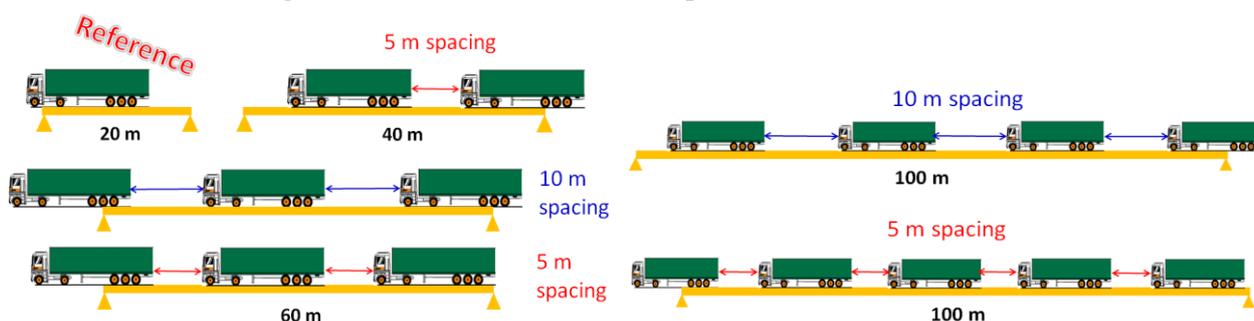


Figure 7 – Multiple presence of trucks in a platoon on a bridge span.

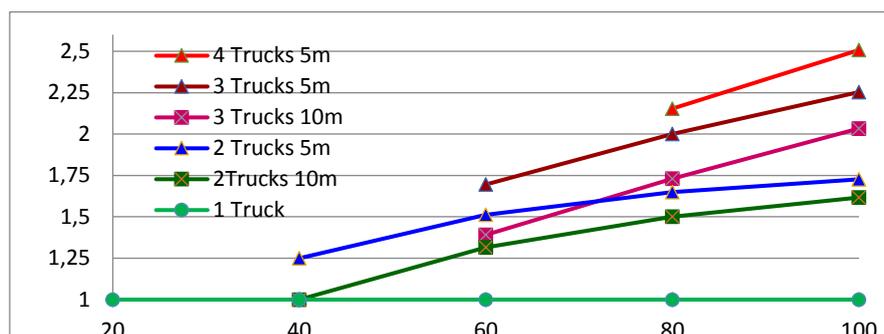


Figure 8 – Bending moment on a simple supported span induced by platoons.

The effect of platoons on pavement wear is not expected being significant, because each trucks acts almost independently, inducing stress cycles proportional to the axle or group of axle loads. However, some further investigations will be carried out, using advanced pavement fatigue models, to account for the hysteresis and time of stress relaxation in bituminous materials. A series of close axles could slightly increase the pavement wear.

5. European Truck Platooning Challenge and ENSEMBLE Project

5.1 European Truck Platooning Challenge (ETPC)

The European Truck Platooning Challenge (ETPC) initiative was launched early 2016 under the Dutch Presidency of the EU. A large demo was organised in some EU Member States with cross-border trips of six mono-brand platoons converging to Rotterdam in the Netherlands (ETPC, 2016). The ETPC opened a long-term vision for the management of heavy goods vehicles on major European corridors. It offers a unique opportunity for manufacturers and OEMs to develop autonomous and intelligent heavy vehicles, and for infrastructure managers to experiment the concept on a large scale, to formulate conditions for its safe and acceptable implementation, particularly for other users and transport companies, and to assess potential benefits. The ETPC promotes cooperation between manufacturers and road authorities. The challenge offers a platform for all partners, industrials, OEMs, logisticians, research institutes and public authorities to strengthen their mutual efforts. The objective is now to allow platoons made up of vehicles of different brands to circulate safely in the EU. An Amsterdam Declaration was signed by the EU Transport Ministers to join their efforts developing autonomous and connected vehicles. A high-level group is continuing this work in relation with ETPC.

The network consists of six supporting associations (steering members): European Automobile Manufacturers' Association (ACEA), Conference of European Road Directors (CEDR), European Association of Automotive Suppliers (CLEPA), Association of European Vehicle and Driver Registration Authorities (EReg), European Shippers' Council (ESC) and International Road Union (IRU). The 6 European OEMs (DAF, Daimler, Iveco, MAN, Scania and Volvo) and research organizations (TNO, University of Amsterdam, IFSTTAR) are members, as well as governmental bodies and other stakeholders from the transport sector. The network comprises about 150 people. The main objectives of ETPC are further developing missions and roadmap:

- To promote truck platooning to provide safer, more efficient freight transport, creating new jobs and economic growth in the traffic and transport sector.
- Fostering cooperation between states, automotive industry, and other related sectors to deploy commercially viable truck platooning services.
- Providing a platform for cross-stakeholder dialogue defining the necessary technical, regulatory and organisational framework.
- Ensuring a coherent, continuous and consistent way forward.

ETPC is raising awareness on benefits of potential truck platooning towards the European Parliament in 2017. ETPC is member of the ENSEMBLE project (section 5.2) supporting the project throughout its member's expertise, representativeness incl. public authorities and expectations, in his capacity of entering in dialogue with the project's members and paves the way to be able to demonstrate the result of ENSEMBLE expected in 2021.

5.2 ENSEMBLE Project

The ENSEMBLE project started in June 2018, as part of the Horizon 2020 framework programme, on multi-brand truck platooning (ART03). The six OEMs are partners in the consortium led by the TNO. The two other research partners are IFSTTAR and IDIADA. ERTICO and CLEPA are among the 17 partners. The project intends to develop standardised interoperable V2V communication, to specify, develop and test on open roads multi-brand truck platoons, to assess the main impacts and to propose mitigation measures against the negative impacts. These two last objectives are led by IFSTTAR in the WP4. The project is planned for 36 months and a total budget of 20 M€.

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