Simulative Assessments of Energy and Space Savings due to Platooning

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Abstract:

Within a platoon, the vehicles are electronically connected and therefore capable of following each other autonomously. Due to this connection the reaction time of the following vehicles is reduced tremendously and enables the vehicles to keep a shorter distance to its preceding platoon member. These shortened intra-platoon gaps are expected to cater for several positive effects. This paper examines the effects of truck platooning n a motorway in regard to gain of road capacity and energy consumption. Eight simulations are conducted, two network elements Motorway Access and Motorway Exit , two lengths of platoons, three truck and six truck platoons as well as two traffic demand developments have been tested. Based on the driving behaviours of trucks on motorways, driving cycles generated from the simulation study serve as input for an energy consumption analysis. The results show that in all the scenarios, the truck platooning of the heavy traffic caused the gain of road capacity of up to 11.9 % and a net energy savings of up to 13 % for the trucks platooning along the motorway. Overall, the study indicates that truck platooning increases the capacity and reduces the energy consumption.

Keywords: Truck Platooning, Capacity Gain, Energy Consumption, Simulative Analysis.

1 Introduction

Platooning is already a widely known concept in the field of intelligent transportation systems. The basic idea is to reduce the gaps between vehicles by driving in an electronically supported convoy, also known as platooning. Due to this direct vehicle-to-vehicle (V2V) communication among the members of such a platoon, it is possible that following vehicles tailing a leading one autonomously.

The present paper shows the results of two different investigations,

- The gain of road capacity due to platooning.
- The energy consumption savings in trucks due to platooning.

2 Platooning

The members of a platoon are connected via a V2V-communication, which provides for an uninterrupted exchange of information, such as speeds and positions, between the convoy companions. These connections cater for very short reaction times of about 0.1 seconds (Daimler AG 2016). Because of this strongly reduced reaction time, the vehicles can drive in minor distances between 10 and 15 m or half a second headway, respectively (Bachmann 2017; DAF Trucks Deutschland GmbH 2016; Daimler AG 2016; MAN SE 2016; Scania AB 2016). The shorter intra-platoon gaps result in slipstream effects which cater for energy savings and emission reductions as well as an improvement in traffic safety (MAN SE 2016). In addition, as seen in Figure 1, an increase of road capacity is expected, due to the reduction of required space (MAN SE 2016).

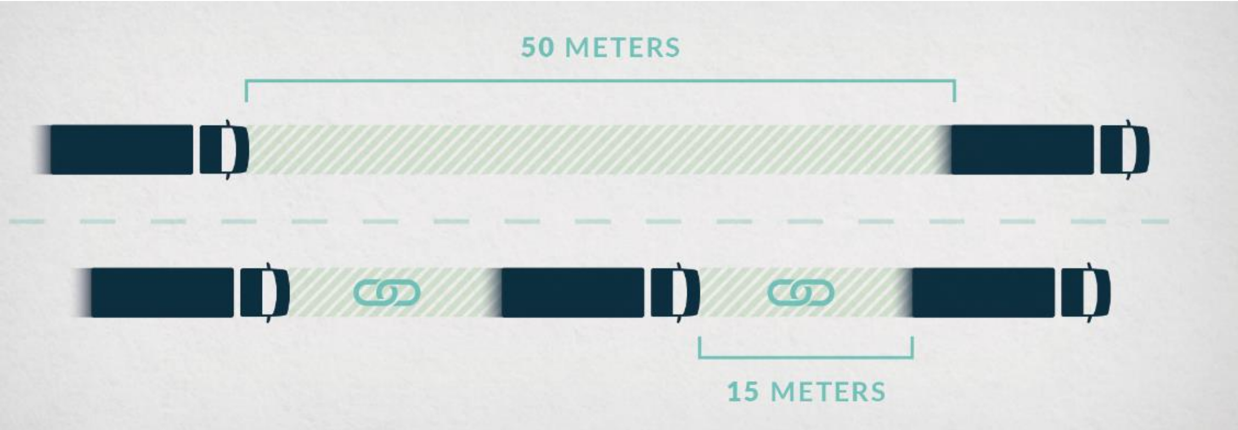


Figure 1. Space savings due to platooning (Continental AG 2016)

3 Gain of Road Capacity

3.1 Methodology

This chapter presents the done investigation and results of Bachmann (2017) about the gain in road capacity on a motorway due to platooning. Eight simulations have been conducted. Two network elements Motorway Access (MA) and Motorway Exit (ME), two lengths of platoons, three truck and six truck platoons and two traffic demand developments (devA and devB) (chapter 3.1.3) have been tested, which are further described in the following. Table 1 shows the setups of the eight simulations.

Table 1. Conducted Simulations for Road Capacity Investigations

Simulation-ID	Network Element	Length of Platoon	Traffic Demand Development
1	MA	three truck	devA
2	MA	six truck	devA
3	MA	three truck	devB
4	MA	six truck	devB
5	ME	three truck	devA
6	ME	six truck	devA
7	ME	three truck	devB
8	ME	six truck	devB

3.1.1 Network elements

The first four simulations were run on a two-lane motorway with a one-lane on-ramp and the second four simulations were done on a two-lane motorway with a one-lane off-ramp. The traffic is in all simulations right-handed. These used network elements come from the German manual for assessment of road traffic facilities (HBS) (Forschungsgesellschaft für Straßen- und Verkehrswesen 2015). Using these elements has two important advantages: Firstly, the HBS clearly defines these elements and contains information about the capacity of those under normal traffic conditions without Platooning, secondly, a simulative method to determine the road capacity has been developed by Geistefeldt et al. (2016), using, among other elements, these very elements which have been calibrated accordingly.

3.1.2 Lengths of Platoons

In the aforementioned simulations (Table 1), two lengths of platoons have been tested three truck platoons and six truck platoons. The number of six trucks in the platoon is taken from the project SATRE (Jootel 2012). One of the outcomes of the project in which actual platoons drove in real traffic was that the maximum length of a platoon which is still acceptable by other road users is 170 m (Jootel 2012). The truck lengths in the here conducted simulations vary between 10.2 and 16.9 m. In case of a six truck platoon in which all six trucks have a maximum length of 16.9 m and an average headway of 12.5 m, the mean of 10 and 15 m (chapter 2), would result in a platoon length of 163.9 m. Moreover, to be able to investigate the influence of different platoon lengths a platoon length of three trucks has been chosen for the second half of simulations.

3.1.3 Traffic Demand Developments

As mentioned above, Geistefeldt et al. (2016) developed a simulative method in order to determine the capacity of a road network. In order to do so over the course of the simulation the traffic demand is increased step by step until the traffic congests. Geistefeldt et al. (2016) also defines six different traffic demand developments to see the influence of the traffic demand onto the road capacity. The different demand developments mainly differ in how fast the demand increases and additionally in case of motorway accesses in the ratio between the demand on the carriageway and the demand on the on-ramp. In the here conducted simulations two demand developments, namely devA and devB, have been used which correspond to the second and fifth demand development line of the six developments defined by Geistefeldt et al. (2016).

In devA, the inflow of traffic is lower as well as the ratio between the increasing demand of the carriageway and the on-ramp. In the case of devB the inflow of traffic on the carriageway is higher than in devA as well as the ratio between the inflow between the main carriageway and the on-ramp rises. In the case of ME the inflow of traffic with devB is also higher than with devA.

3.1.4 Calculation of the Road Capacity

To calculate the capacity of the motorway with the method developed by Geistefeldt et al. (2016), the traffic needs to collapse. This is achieved by increasing the traffic demand step by step. It reaches the by the HBS defined road capacity after approximately 70 simulations minutes (Forschungsgesellschaft für Straßen- und Verkehrswesen 2015). To be certain that the collapse of the traffic will be achieved the here conducted simulations ran for 100 simulation minutes.

As input data for the calculation serves the average velocity on the right lane of the main carriageway before the ramp as well as the traffic volume on the main carriageway right after the ramp. These are being collected in the same interval of five simulation minutes in which also the traffic demand is increased. With 20 simulation runs for each simulation and 20 simulation intervals per run in total 400 values for each average velocity and traffic volume have been collected. Figure 2 shows the results of the second simulation with ME as network element, six truck platoons and devA as demand development (Table 1).

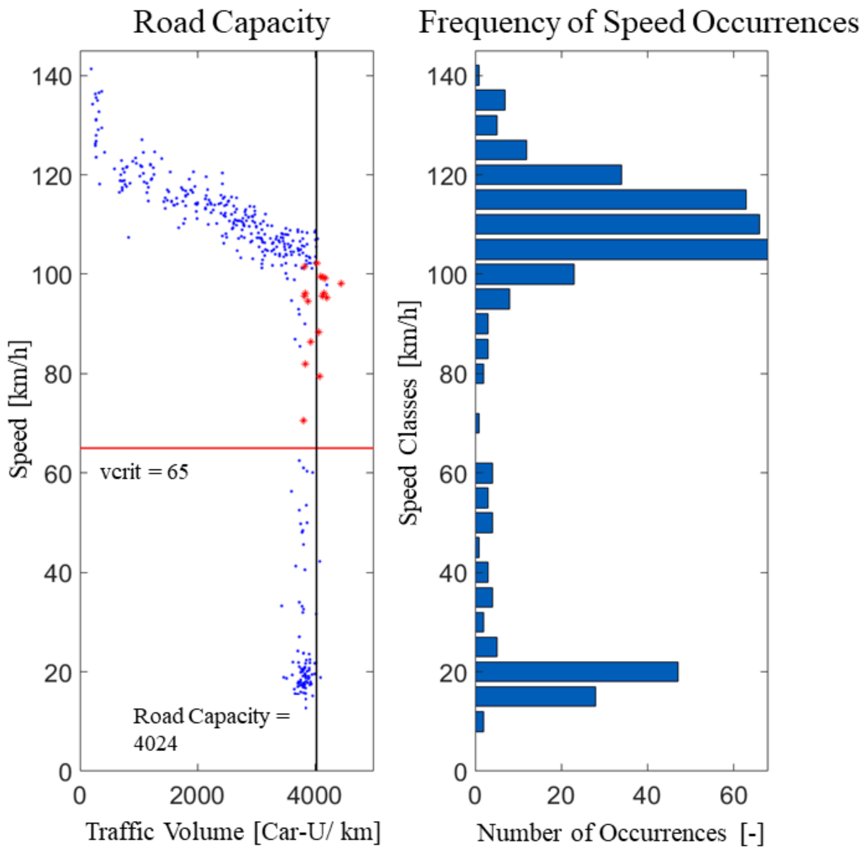


Figure 2. Result from the Second Simulation (Table 1) (Bachmann 2017)

Firstly, the critical velocity (vcrit) needs to be determined. This is done by sorting all measured average speeds into speed classes and then count the number of occurrences of this very class. A speed class consist of all measured speeds within a range of five kilometres per hour (km/h). For example, the speed class 60 includes all collected speed samples between 57.5 km/h and 62.5 km/h. The vcrit is understood as the speed with the lowest frequency of occurrences between the speed classes 60 km/h and 80 km/h. In cases such as the one depicted above, where two speed classes occur equally seldom, the lower speed class is chosen. Therefore, vcrit is 65 km/h in the shown case.

Secondly, two subsequent speed measurements are searched in which the first value is higher than vcrit and the second is lower than vcrit. Additionally, the values must differ by at least 15 km/h. In the left graph of Figure 2 the red stars mark the measurements where the subsequent measurement fulfils the mentioned criteria. At each simulation interval, every five simulation minutes, not only the average velocity but also the traffic volume is collected. Therefore, each speed can be associated with a certain traffic volume. This relation is used here to determine the road's capacity. The average traffic volume of the earlier identified measurements (red stars) is the capacity of the road. In this case, the road has a capacity of 4024 car-units per hour (Car-U/h). Car-unit expresses the whole traffic in one unit, for example does a car has one car-unit whilst a truck has two (Forschungsgesellschaft für Straßen- und Verkehrswesen 2015; Geistefeldt et al. 2016).

4 Energy Savings Analysis

Platooning of vehicles, have numerous benefits as discussed above including improved overall efficiency of the vehicle. The increase in the efficiency is due to the reduction in the aerodynamic drag of the vehicles participating in the platoon. This includes the energy reduction even in the lead vehicle (Guttenberg et al. 2017).

Figure 3 shows the influence of aerodynamic drag on energy consumption with increase in vehicle velocity. On motorways, with vehicle speed more than 80 km/h the aerodynamic drag has more influence on the energy consumption. The reduction in energy consumption is studied by implementation of a longitudinal simulation model. The simulation is performed in MATLAB that include calculation of the total resistance forces encountered by the vehicle and thereby evaluating the total power consumption.

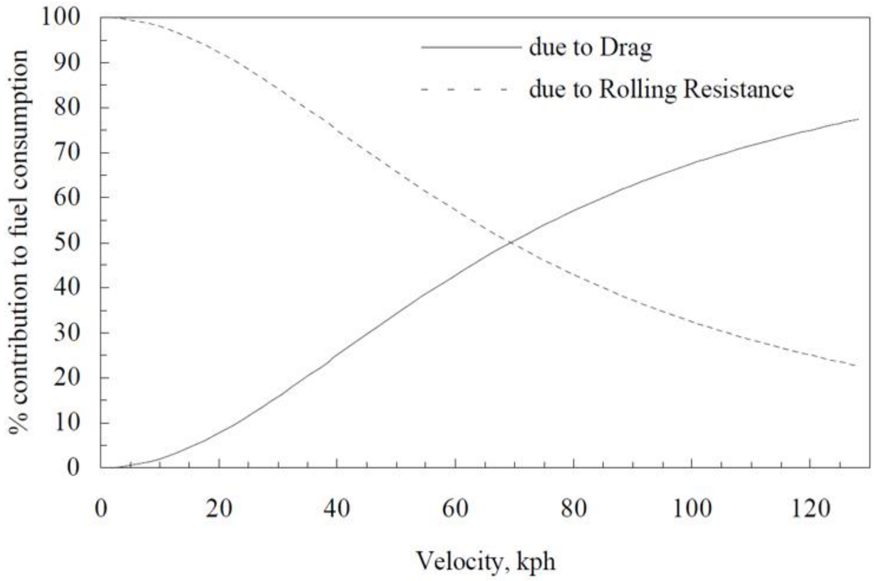


Figure 3: Fuel consumption due to drag and to rolling resistance as a percentage of total fuel consumption (Zabat et al. 1995)

The total resistance experienced by a vehicle is the sum of the drag resistance, the rolling resistance, the gravitational or climbing resistance and the acceleration resistance. However, as discussed above, the only component that affects the total resistance while platooning is the aerodynamic drag. Hence, the impact of platooning on the energy consumption primarily depends on the force used to overcome the aerodynamic drag. The powertrain components play an important part in the analysis and simulation model has fixed motor efficiencies for motor, inverter and the transmission. The longitudinal dynamics model is completely adapted from the simulation by Sethuraman et al. (2019). However, all the vehicle parameter and the performance parameters are changed and listed in the Table 2: Vehicle Input Parameters. The driving behaviour of the trucks are different as well. So, three different driving scenarios were chosen for the longitudinal simulation based on the operation of the trucks.

Table 2: Vehicle Input Parameters

Characteristic	Unit	Value
Vehicle length	m	15
No of trucks	-	1 to 6
Vehicle spacing (Intra-platoon distance)	m	10 and 15
Drag coefficient	-	0.60
Rolling resistance Coefficient	-	0.010
Air density	Kg/m3	1.184
Powertrain efficiency	-	0.8
Span area of the vehicle frontal area exposed to air resistance	Sq.M	9.5
Driving cycle	• NREL Driving Cycle (Typical Highway cycle) • MA Driving cycle • ME Driving cycle	

The standard NREL driving cycle (Typical highway cycle) which is a convention motorway driving cycle used for longitudinal simulations (NREL-DriveCAT 2019). Figure 4 shows the segment of two simulated driving profiles, which were gained from the investigations regarding the road capacity (Table 1). The blue driving cycle comes from the motorway access scenario and the red driving cycle from the motorway exit scenario (chapter 3.1.1). The obvious difference between the two driving cycles can be explained by the interaction of the platoons with other road users as explained in chapter 5.1.1. The driving profiles segments were chosen based on high congestion scenarios in the regions of motorway access and motor way exit to identify the benefits of platooning in realistic scenarios.

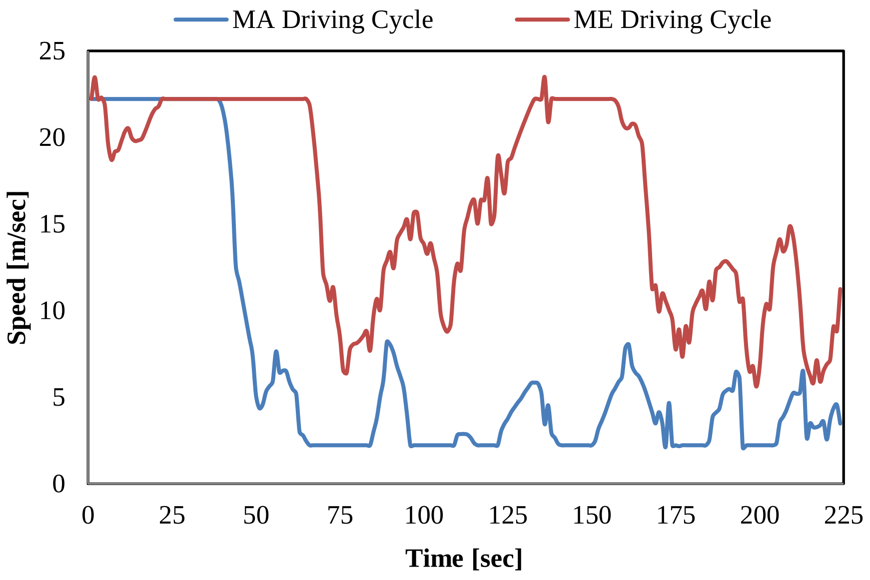


Figure 4: Simulated MA and ME driving profiles

4.1 Drag Reduction Analysis

The PATH program of the University of California (Zabat et al. 1995), conducted experiments to study the effects of platooning and estimate the effects of intra-platoon distance. From this study, the average coefficient of drag of the platoon is less when compared to single vehicle and the reduction the average drag is influenced by the intra-platoon distance between vehicles and the number of vehicles in the platoon. Therefore, the drag force of the vehicle (C_d) in a platoon is calculated by replacing the original drag co-efficient with the average drag co-efficient of the platoon.

Figure 5 shows the average drag coefficient reduction per vehicle ($C_{d(\mathrm{Avg})}$) in the platoon as a function of the intra-platoon distance and the number of vehicles in the platoon (Guttenberg *et al.*, 2017). The drag coefficient reduction is expressed as the ratio of the average drag coefficient of the platoon to the drag coefficient of a single bus.

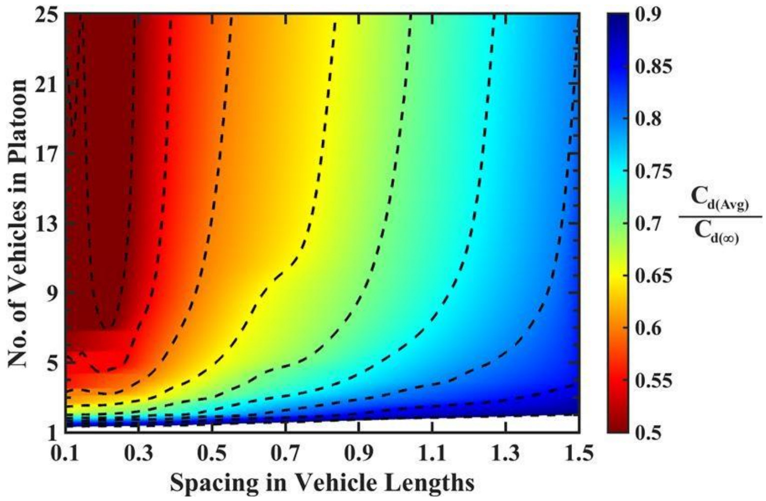


Figure 5: Relation between Drag Reduction Factor, Vehicle Distance and No. of Vehicles in Platoon (Guttenberg et al. 2017)

Therefore, the drag force is calculated by replacing (C_d) with $C_{d(\mathrm{Avg})}$) based on the research results from (Guttenberg et al. 2017).

$$F_{Drag} = \frac{1}{2}\rho_{air} {v_v}^2 C_{d(\mathrm{Avg})} A_v \qquad (1)$$

where:

F_{Drag} is the drag resistance in N;

ρ_{air} is the air density in kg/m3;

v_v is the velocity of vehicle in m/sec;

A_v is the frontal area of vehicle in m2.

4.2 Design of Experiments

To evaluate the energy savings in trucks due to platooning, two scenarios were considered.

1. Six trucks platoon with an intra-platoon distance of 10 m.
2. Six trucks platoon with an intra-platoon distance of 15 m.

For each scenario, the simulations are performed for three different driving cycles: 1: The NREL driving cycle 2: The MA driving cycle and 3: The ME driving cycle. During the analysis, for every driving cycle the number trucks in the platoon is increased from one to six. For every simulation, due to the change in the number of trucks and intra-platoon distance, the coefficient of drag is changed correspondingly.

The reduction in drag coefficient of the platoon of trucks for the two different scenarios is shown in Figure 6. The plot shows reduction in average drag for trucks in the platoon. From the plot, it can be seen that the average drag co-efficient of the platoon decreases with increase in the number of trucks in the platoon. It can be deduced that the coefficient of drag reduces up to 32.5 % for a six truck platoon with 10 m intra-platoon distance and 25.5 % for a six truck platoon with 15 m intra-platoon distance. In addition, the reduction in drag reduces with an increase in the number of trucks in the platoon. For instance, the for a 3 truck platoon with 10 m intra-platoon distance has an overall drag reduction of 25 % in comparison to 32.5 % for six trucks.

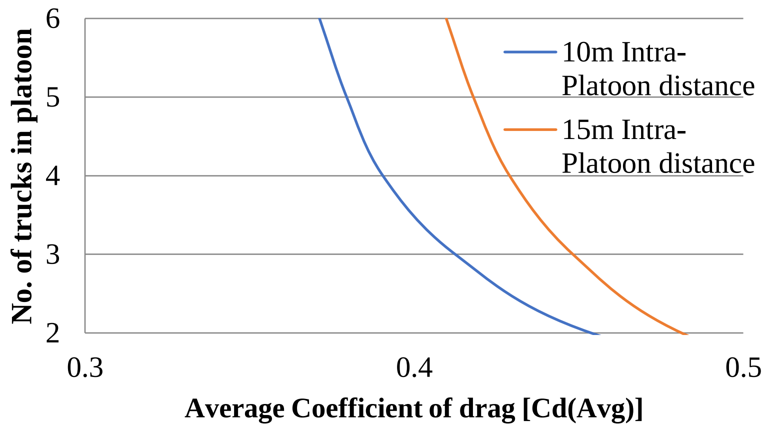


Figure 6: Impact of Platooning on the Drag Coefficient

Hence, in total over 48 individual simulation runs were performed to evaluate and understand the impacts of platooning on energy consumption.

5 Results

5.1 Outcome of the Capacity Gain Investigations

5.1.1 Interaction of the Platoons with other Road Users

In order to understand the outcome of the simulations it is necessary to understand some of the behaviour patterns of the platoons when interacting with other road users. The platoons are solely operating on the right lane of the main carriageway of the motorway. In the scenario of the motorway access road users coming from the on-ramp want to switch from the acceleration lane onto the right lane of the main carriageway. Naturally, situations occur in which a car wants to do such a manoeuvre whilst a platoon is passing the acceleration lane on the right lane of the main carriageway. In these cases, the platoon extends the intra-platoon-distance between the two corresponding platoon members as shown in Figure 7. However, this only happens if the road user fulfils certain criteria, such as having a sufficient speed and is not driving right next to a truck but parallel to an intra-platoon gap. Otherwise, the platoon “ignores” the vehicle and continues its journey, because the platoon members would have to reduce their speed too intensely.

If that is the case, the road user has to slow down or even stop until the platoon passed and it can switch lanes behind it. In the scenario of the MA this waiting happens on the on-ramp and acceleration lane, respectively. In the scenario of the ME this waiting of road users happens on the left lane of the main carriageway, which can lead to traffic jams on the main carriageway.

In order to investigate the effects of this behaviour not only concerning the road capacity but also about the energy consumption, two driving cycles were derived from the simulations named in Table 1 and analysed in chapter 4.

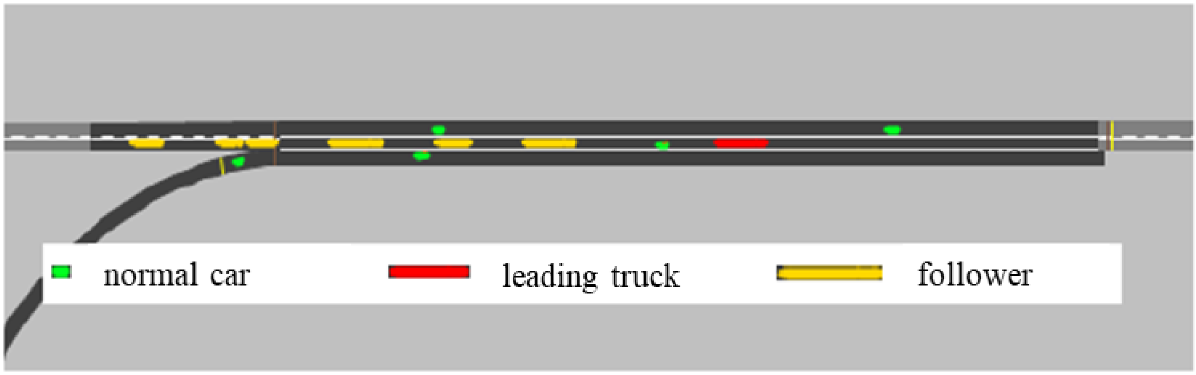


Figure 7. Road User is Crossing Through a Platoon (Bachmann 2017)

5.1.2 Results of the Capacity Gain Investigations

The here calculated road capacities were then compared with the scenario of no truck platooning. The capacity values for this scenario were taken from Krause et al. (2017). Figure 8 depicts the proportional capacity gain compared to the non-platooning scenario. The diagram clearly shows that in all tested scenarios capacity is gained from 0.9 % up to 11.9 %.

However, the graph also shows that the capacity gain differs quite a lot in the distinct simulation setups. While there is a more comparable capacity gain in case of the MA between 5.0 % and 6.9 %, the simulation results in case of the ME differs quite lot and lie between 0.9 % and 11.9 %. There is also a difference between the different platoon lengths. While in the MA scenario there is more capacity gained by the longer six truck platoons with a difference up to 1.7 %, in the ME scenario the shorter three truck platoons gain more capacity with a difference up to 4 %.

Moreover, the two demand developments cater for different outcomes, while in the MA case there is insignificant difference of up to 0.5 % of capacity gain, in the ME case it is up to 9.3 % if one compares the same platoon lengths.

The different outcomes of this investigation can be explained by the distinct platoon behaviour patterns in certain situations, discussed in chapter 5.1.1 and is further elaborated in chapter 6.1.

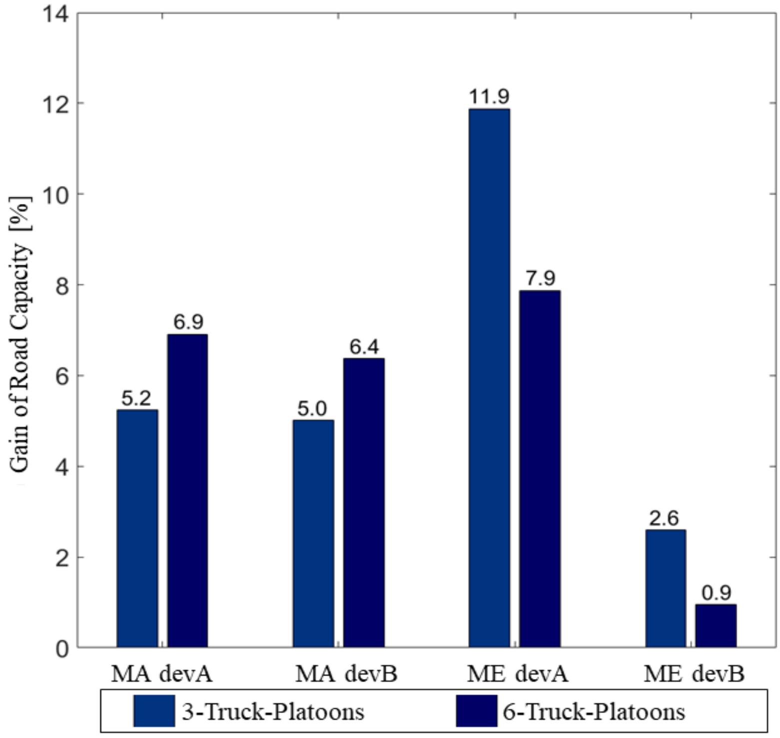


Figure 8. Gain of Road Capacity (Bachmann 2017)

5.2 Results of Energy Savings Analysis

From the experiments, there is a significant energy savings due to reduction in the coefficient of drag. Figure 9 shows the results of the net energy savings due to platooning of trucks driving through the conventional NERL driving cycle. It can be seen that, the energy saving can be up to 13% for the six trucks platoon with 10 metre intra-platoon distance and 11 % for the three trucks platoon with 10 metre intra-platoon distance. The results show that the there is a strong influence on the intra-platoon distances and the number of vehicles in the platoon.

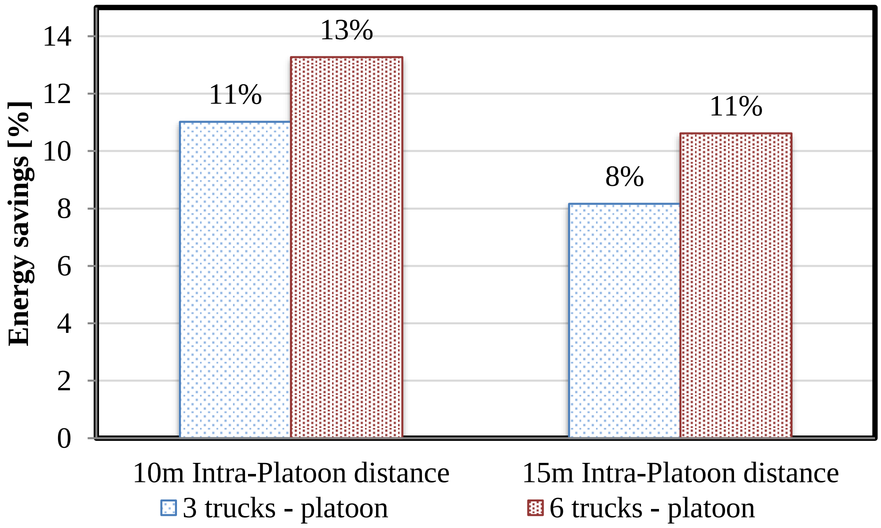
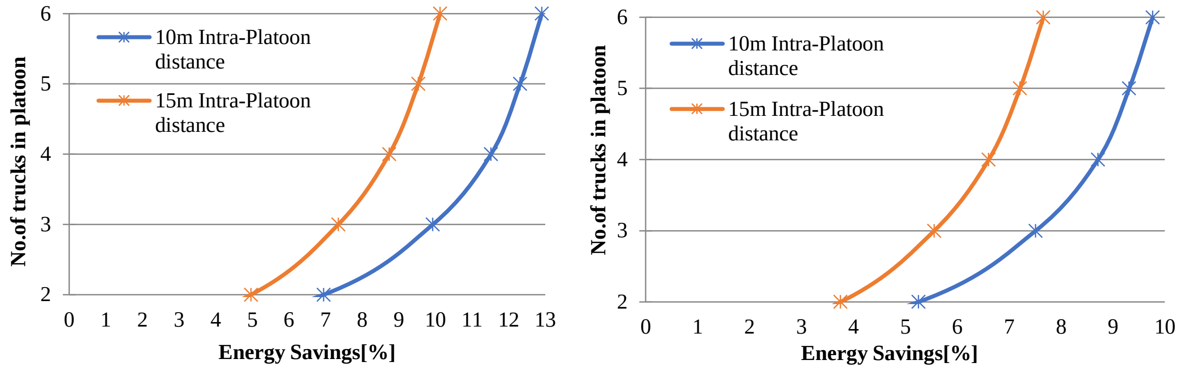


Figure 9: Energy saving of truck platoon (NREL driving cycle)

The following (a) and (b) show the savings in energy consumption due to platooning in two different simulated driving cycles, the MA driving cycle and the ME driving cycle respectively. (a) shows that the energy savings of all the trucks (up to 6 vehicles) in the platoon with 10 and 15 m intra-platoon distance has an average energy savings of 13 % and 10 % respectively.



(a) *(b)*

Figure 10. Impact of Platooning on Energy Consumption (MA Driving Cycle) (b): Impact of Platooning on Energy Consumption (ME Driving-Cycle)

Figure 10 (b) shows the energy savings of all the vehicles in the platoon (up to 6 vehicles) with 10 and 15 m intra-platoon distances has average energy savings of 9.7 % and 7.6 % respectively.

The exit driving cycle has a lesser net energy savings in comparison to the trucks in access driving cycle. This is because of the driving characteristic of both the cycles as seen in Figure 4. The speed of trucks in MA driving cycle has a lower speed and the deviation in the speed is also observed to be lower. Hence, the energy consumption of the trucks entering the motorway is lesser in comparison to the trucks exiting the motorway. This leads to the 3 % addition savings.

From the above plots, it is seen that the energy savings of the platoon is increasing with no. of trucks in the platoon. However, the magnitude of the increase in the energy savings per truck is less. In addition, the energy consumption of the platoon is minimum when the trucks are moving closer to each other.

6 Conclusions

6.1 Gain of Road Capacity

This paper presented the investigations of Bachmann (2017) on road capacity gain on motorways and examined the energy consumption savings due to truck platooning. Eight simulations with different setups were conducted (Table 1). The results (Figure 8) showed quite some differences between the distinct simulations setups.

In the MA scenario the lower capacity gain of three truck platoons of 5.2 and 5.0 % compared to the capacity gain of the six truck platoons of 6.9 and 6.4 % can be explained with the higher number of reduced gaps within the longer platoons. In addition, the lower capacity gain in case of the devB compared to devA with a difference of up to 0.5 % was expected due to the higher traffic inflow (chapter 3.1.3).

In the ME scenario the six truck platoons gain less capacity than the three truck platoons with a difference between 1.7 to 4.0 % which is understandable considering the platoon behaviour patterns described in chapter 5.1.1. Cars waiting on the left lane cater for lesser capacity gain than cars waiting on the on-ramp. The difference between the demand developments of up to 9.6 % shows that the higher traffic inflow has a tremendous negative influence in combination with cars waiting on the left lane on the capacity of the motorway. Therefore, it is clear that situations in which cars have to queue on the left lane have to be avoided.

The here two tested scenarios, MA and ME, are rather “platooning-unfriendly” scenarios because cars have to pass through the platoons, on longer stretches without on- and off-ramps a higher capacity gain is to be expected. Consequently, longer networks with such stretches have to be simulated to win more realistic and comprehensive results. Nevertheless, the here presented investigation already showed clearly that even in “platooning-unfriendly” scenarios, platooning causes a gain of road capacity on motorways and even higher gain is to be expected in more realistic scenarios.

6.2 Energy Savings

This study analysed the impacts of platooning on energy consumption of trucks in all modes of operation such as accessing the motorway access, cruising and motorway exit. The results of vehicle simulation results show that there is a significant savings in the energy consumption due to the platooning of trucks. There is a net energy savings of up to 13 % for the trucks platooning along the motorway. We also observed that the energy saving was up to 13 % and 10 % for the MA and ME cycles respectively. It can be seen that the reduction in aerodynamic resistance is lesser with increase in the number of trucks and might saturate beyond 8 to 10 trucks in a platoon. Hence, having more than seven trucks 8-10 trucks in the platoon does only yield less in terms of energy savings. It may have other benefits in terms of traffic volume and congestion; nevertheless, it is necessary to investigate. This study investigated the reduction in drag based on the experimental results published earlier. Hence, to have accurate results, computational fluid dynamics simulations of individual trucks and platoon have to performed and analysed. However, it can be concluded that the platooning of trucks definitely has a great positive impact in terms of energy savings during its entire operation.

7 References

Bachmann, Frederik Reinhard (2017): Simulative Wirkungsuntersuchung eines Kolonnenassistenten auf die Kapazität der Fernstraßeninfrastruktur. Master's Thesis. Technical University of Munich, Munich. Department of Civil, Geo and Environmental Engineering, Chair of Traffic Engineering and Control. Available online at https://mediatum.ub.tum.de/1328897?query=Simulative+Wirkungsuntersuchung&show_id=1415808, last checked on 19.12.2018.

Continental AG (Hg.) (2016): Up to 15 Percent Less Consumption – Continental Focuses on Automated Truck Convoys. Available online at http://www.continental-corporation.com/www/pressportal_com_en/themes/press_releases/1_topics/automated-driving/pr-2016-09-02-platooning-en.html, last checked on 08.02.2017.

DAF Trucks Deutschland GmbH (Hg.) (2016): „EcoTwin“ nimmt an EU Truck Platooning Challenge teil. Available online at http://www.daftrucks.de/de-de/news-and-media/news-archive/articles/global/2016/q1/22032016-ecotwin-participating-in-the-european-truck-platooning-challenge#, last checked on 07.02.2017.

Daimler AG (Hg.) (2016): Vernetzte Lkw. Mithilfe des Internets zum Warentransport der Zukunft. Available online at https://www.daimler.com/innovation/vernetzung/vernetzte-lkw.html, last checked on 05.02.2017.

(2019): Drive Cycle Analysis Tool — DriveCAT | Transportation Research | NREL. Available online at https://www.nrel.gov/transportation/drive-cycle-tool/, last checked on 28.07.2019.

Forschungsgesellschaft für Straßen- und Verkehrswesen (Hg.) (2015): Handbuch für die Bemessung von Straßenverkehrsanlagen. HBS. Ausg. 2015. Köln: FGSV-Verl.

Geistefeldt, Justin; Giuliani, Stefan; Busch, Fritz; Schendzielorz, Tobias; Haug, Andrea; Vortisch, Peter et al. (2016): HBS-konforme Simulation des Verkehrsablaufs auf Autobahnen. In: *Schriftenreihe der Bundesanstalt für Straßenwesen, Verkehrstechnik* (V 279).

Guttenberg, Matthew; Sripad, Shashank; Viswanathan, Venkatasubramanian (2017): Evaluating the Potential of Platooning in Lowering the Required Performance Metrics of Li-Ion Batteries to Enable Practical Electric Semi-Trucks. In: *ACS Energy Lett.* 2 (11), S. 2642–2646. DOI: 10.1021/acsenergylett.7b01022.

Jootel, Paviter S. (2012): SARTRE - SAfe Road TRains for the Environment. Project Final Report. Hg. v. SARTRE-Consortium. Available online at www.sartre-project.eu, last checked on 26.03.2017.

Krause, Sabine; Motamedidehkordi, Nassim; Hoffmann, Silja; Busch, Fritz; Hartmann, Martin; Vortisch, Peter (2017): Auswirkungen des teil- und hochautomatisierten Fahrens auf die Kapazität der Fernstraßeninfrastruktur (296). In: *FAT*.

MAN SE (Hg.) (2016): Platooning by MAN Truck & Bus. Available online at http://www.man-truckers-world.de/de/2016/04/04/platooning-by-man-truck-bus/, last checked on 03.02.2017.

Scania AB (Hg.) (2016): Important next step for autonomous vehicles. Available online at https://www.scania.com/group/en/important-next-step-for-autonomous-vehicles/, last checked on 07.02.2017.

Sethuraman, Ganesh; Liu, Xiaodong; Bachmann, Frederik Reinhard; Xie, Meng; Ongel, Aybike; Busch, Fritz (2019): Effects of Bus Platooning in an Urban Environment (Accepted). In: IEEE - Intelligent Transportation Systems Conference 2019. Auckland, New Zealand.

Zabat, Michael; Stabile, Nick; Farascaroli, Stefano; Browand, Frederick (1995): The Aerodynamic Performance Of Platoons: A Final Report. Presented to the California Department of Transportation Partners for Advanced Transit and Highways (PATH) Program. California PATH Research Report. Available online at https://escholarship.org/uc/item/8ph187fw, last checked on 03.04.2019.